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INITIAL WIND TUNNEL TESTS OF A MAGNETICALLY-SUSPENDED SPINNING AND CONING OGIVE CYLINDER

MASSACHUSETTS INSTITUTE OF TECHNOLOGY AEROPHYSICS LABORATORY

by

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FINAL REPORT

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The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

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

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TABLE OF CONTENTS

LIST OF FIGURES

Introduction

For the past three (3) years members of the staff of the M.I.T. Aerophysics Laboratory have been conducting a research program with the magnetic balance system (1) aimed at studying the Magnus effect on bodies of revolution undergoing simultaneous spinning and coning motion. This research program was stimulated by the possibility that introduction of an additional degree of freedom might lead to a better understanding of recent measurements of the Magnus force on ogive cylinders (2) and phenomena observed in surveys of the wakes behind these cylinders (3). This Final Report describes the work done to obtain initial data on a spinning and coning ogive cylinder.

The experimental study of spinning and coning bodies required several innovations in magnetic balance techniques. These include:

1. Means of driving the model simultaneously in pitch and yaw to produce a coning motion;

2. Means of nulling unwanted motion in other degrees of freedom; i.e., drag, lift and slip;

3. Means of monitoring model position and using results from Items (1) and (2) to maintain a constant amplitude coning motion with a minimum of unwanted motion during an experiment;

4. Means of high precision dynamic recording of both the unsteady and steady balance currents, and the phase shift between lift and angle of attack during a run to reveal the influence of coning on the Magnus coefficient;

5. Means of reducing the data to obtain the relative force information. This has been reported by Bisplinghoff (4) for a pitched model. An extension of his technique to include both pitch and yaw angles is described below.

6. Means of spinning the model while undergoing coning motion;

7. Means of interpreting experimental measurements to sort out effects of spinning and of coning.

In the past three years progress has been made in all the above areas to the point where preliminary data was acquired with a model spinning at 100 rps while coning at 2 Hz at amplitudes of 2.5°, 5° and 7° half angle and velocities up to 300 fps.* As far as we know, this is the first time anywhere that motion this complex has been produced, monitored and adjusted using a magnetic balance system.

Producing Model Motion

During the first two years of the research program efforts were directed to Areas 1-5. As in previous studies (1,4) model spin was induced by applying a rotating 1200 Hz

*Use of new power supplies (5) should extend this range in future work.

magnetic field transverse to the wind tunnel test section. This field was generated by the same coils which control model pitch and yaw by superimposing a 1200 Hz current on the D.C. current. Simultaneous spinning and coning motion was produced on a spinning model by introducing sinusoidal perturbation signals into the pitch and yaw control systems. These signals were generated by a master oscillator and were variable in amplitude and in phase with respect to this reference signal. Because of asymmetries in the magnetic circuits, the signals required to produce a circular motion of the nose are not quite equal in amplitude and differ slightly in phase from ideal time quadrature. Model motion in response to these signals in pitch and yaw was a coning motion superimposed on a small plunging and axial motion of the center of gravity. It was found that by introducing additional position perturbation signals in lift and drag the resulting motion could be made purely spinning and coning with the center of gravity remaining fixed. In order to produce the required position perturbation signals, a 16 channel signal source was designed and constructed. It is shown in Figure 1.

This circuit uses three of the four fixed phase output channels (0^o, 90^o, 180^o, 270^o) of the Spectral Dynamics SD104A5 oscillator as inputs to phase shift bridge networks and variable gain I.C. amplifiers. This provides nearly independent gain and phase adjustment over the 90 degrees between inputs, as presently connected nulling signals are available from 0-360 degrees. In order to adjust the coning amplitude of all channels, a master gain control consisting of three mechanically coupled 10 turn 100K potentiometers was constructed and placed before the phase adjusting chassis.

The system developed for monitoring model and coning motion used the optical transits to calibrate the electric position sensor signals which were displayed on oscilloscopes as Lissajous figures. Pitch and yaw signals were displayed on one oscilloscope, lift and slip on a second and drag on a third. Gains on the first oscilloscope were set so that when the model coned, a circle was produced as the model made one coning cycle. Four points on this circle were calibrated by using the transits to set the model position successively in pitch, yaw, -pitch, -yaw, equal to the desired coning angle. These preset positions were marked on the oscilloscope face and used as index marks to establish model position during a run. Because of drift in the EPS system it was necessary to re-establish this reference position frequently--every 15 to 20 minutes. This was a significant source of position error.

The other two oscilloscopes were used only as null indicators to permit adjustment of lift, slip and drag perturbation to produce the minimum model motion in these degrees of freedom. The resultant motion, usually a few percent of the nose motion, was probably a result of harmonic content in model response (4).

In the course of operating with a spinning and coning model it became apparent that balance performance had to be compromised in order to find control settings that would allow the combined motion.

The control settings which are optimum for a non-spinning coning model cause instability for a spinning model. Additional compensation circuitry which will properly correct for model spin is needed to improve this situation. Circuits have been designed; they should be constructed and tested in future work.

Data Acquisition

After the desired spinning and coning motion is produced, the forces needed to maintain this motion must be accurately measured. This proved to be the most difficult part of the research program for several reasons.

First, the desired information is more extensive than has been measured in the past. All balance measurable quantities, which for static tests have steady values, are periodic at the coning frequency. This means that in the simplest case where motion is simple harmonic, each channel has phase and amplitude which must be recorded. In the case of more complicated motion, wave shape as well can be variable.

Second, because of the necessity of providing spin torque, the noise level is increased by the roll drive power.

Third, because of the complex model motion, balance compensation must be compromised from the steady case optimum settings. This causes random disturbances in model motion to be more severe than normal.

Two methods of data acquisition have been devised in an effort to overcome these difficulties. Only the first, however, could be included in the tests presently being reported. Equipment and connections for both methods are shown in Figure 2.

In the first method the Sanborn oscillograph and digital voltmeter are used to record magnet current data and position reference signals. Because of the large inertial forces on the model an attempt was made to record only the part of the force signal due to the aerodynamic loads using the following procedure.

The Spectral Dynamics 104A master oscillator supplies four 90^{o} phase-shifted signals at the desired coning frequency. These are simultaneously attenuated by the master coning control and are fed to two nulling drive panels which split the signals into eight channels, each having independently adjustable phase and gain. One set of these (position drive) inputs are routed to the input of the magnetic balance servo amplifier. Here pitch and yaw are adjusted to produce the coning motion; and lift, slip and drag are adjusted to null out unwanted motion in these degrees of freedom. The remaining channels are subtracted from the oscillograph inputs to produce a null output when the model is spinning and coning wind off. Model spin is provided by a roll drive oscillator feeding two 2 Kilowatt amplifiers connected to the pitch and yaw coils. These are operated at 1200 Hz and produce some cross coupled noise at the oscillograph inputs. (Experience to date indicates that additional filtering is needed here.)

During a run, model motion is monitored on three dual beam oscilloscopes which are connected directly to the electric position sensor outputs as described above.

The coning amplitude is then increased to the desired level wind off, as determined from the oscilloscope, and the nulls on both position and recorder input are adjusted.

The coning gain is then temporarily reduced and the desired test velocity is established. The coning gain and position are then readjusted to reproduce the desired coning motion and data is recorded on both the oscillograph and integrating digital voltmeter with printer.

The drawback to this method is that if model position history is not exactly reproduced during wind-on data acquisition, the nulling signals contribute unknown errors. This is believed to be the cause of the large scatter in the data reported below. Future data will be recorded, including all forces and moments, without any attempt to cancel out the inertial loads. The inertial loads will be calculated and subtracted in the data reduction process.

The second method using the Spectral Dynamics tracking filters should greatly reduce the noise problem because of the synchronous-rectification in the Spectral Dynamics system. This reduces noise and provides D.C. outputs proportional to amplitude and phase. These can be recorded with the DVM or monitored on panel meters. This combination should be tested in future work. It is expected to provide much more accurate measurement of amplitude and phase than can be obtained from oscillograph records. However, only one channel at a time can be processed.

A recent study by Luh (6) of the application of digital computers to magnetic balance systems appears to provide a very promising method for acquiring data on a spinning and coning model. Because of the speed of the digital computer such a digitally controlled magnetic balance would have the capability to record instantaneous data at 30 or more points around the coning cycle and efficiently reduce the data based on exact instantaneous model positions.

Data Reduction

Calibration procedures have been developed for models at high angles of attack (4). These indicate that the force and moment calibration constants must be determined as a function of pitch and yaw angle for angles above 5 to 10 degrees. The problem of calibration (and also model position determination during a run) is much more difficult when both pitch plane and yaw plane angles are involved. For compound angles the laser position system cannot be used for calibrations. A sample calibration using Bisplinghoff's technique (4) was carried out using the transits for angular measurement.

Calibration points were selected at 8 points around the coning circle of 8.50° coning angle, as shown in Figure 3. Loads were applied of 0, 20, 40 and 60 grams. Three methods of applying load combinations were used and a computer program was developed for each method.

Method 1 - Loads were applied in three separate tests, drag only, combined lift and pitching moment, combined side force and yawing moment. The combinations were chosen because these resulted from applying the load at the model nose, a mechanical device to apply pure moments being very difficult to construct and use accurately. This method provided the fewest nonzero terms in the calibration equation sets.

Method 2 - Loads were applied in two separate tests: drag plus lift combined with pitching moment and drag plus side force combined with yawing moment.

Method 3 - Loads were simultaneously applied along all axes in one test: drag plus lift combined with pitching moment plus side force combined with yawing moment. A computer program was written to solve the calibration equations in each case and the results were compared to Bisplinghoff's (4) at zero yaw angle. The accuracy of this calibration technique could not be evaluated because of scatter in the calibration data. As had been found by Bisplinghoff, model position control using the EPS and transits alone produced too much data scatter to give an accurate evaluation of the data reduction technique. It was evident, however, that Method 3, which is the least time-consuming, produced the best results. This is consistent with the following description.

Using Method 3 the time to complete a calibration was minimized. Thus corrections for position drift were fewer. Also, using Method 3 more terms in the coefficient matrix were numbers other than zero, thus the addition of random noise inputs to the matrix elements caused the smallest effect in the calculated results for this case.

The results for Method 3 were in general agreement with Bisplinghoff's measurements for the pitch plane subject to the scatter already mentioned. The calculation determined by Method 3 was used for reduction of the initial data reported below. The results of this calibration study indicate that the method of calibration and data reduction developed for a pitched and yawed model is adequate for the present needs and is sufficiently good that improvements in positional stability will be required before any deficiencies in the data reduction method can be found.

Initial Results

Initial wind tunnel tests of the 5-caliber ogive cylinders tested previously under static conditions (2,3) were carried out in the subsonic wind tunnel using the spinning and coning apparatus of Figure 2 and the magnetic balance system. The test procedure has been described above. These tests used a Sanborn 6-channel recording oscillograph to monitor the time varying component of the magnetic balance currents as well as pitch position. The time average part was recorded with the Hewlett-Packard integrating digital voltmeter and printer.

The results of these seventeen initial runs are given in Table 1. In an effort to remove the wind-off tare loads needed to produce model motion, the signals measured were the difference between the current signal and a phase and amplitude controlled nulling signal, which was adjusted to provide near zero output wind off. Any error in this nulling procedure resulted in a directly measured error signal. Model position drift is the main cause of this error in nulling, which is believed to be the cause of the large scatter in the data of Table 1 and is probably due in part to electronic position sensor drift and in part to clipping in the side force power supply. The oscillograph records, Figures 4 and 5, show that clipping was present in Run 17. Normal force components for a nonconing laser stabilized model at PD/2V = .045 are given in the last column of Table 1 for comparison. These show that the measured values for C_L and C_Y are of the right size but the large amount of scatter precludes any comparison between spinning, coning-nonspinning, and spinning and coning results.

Table 1

Initial Data on Spinning and Coning Ogive Cylinder
$\ell/D=5$ Coning Frequency 2 Hz. Opposite to Spin

	Coning Amplitude											
Run	Pitch Angle	Yaw Angle	Speed fps	Spin Rate rps	Oscillo-graph Figure Number	Lift Current mv**	Lift Current Phase Angle	Side Force Current mv**	Side Force Current Phase Angle	C_{L}*	C_{Y}*	Normal Force Coefficient Non-Coning
1	2.5°	3°	150	0		9.5	13°	11.5	81°	.100	.114	.12/.14
2	2.5	3	300	0		37.0	11	48.0	93	.095	.115	.11/.13
3	2.5	3	300	0		38.0	11	47.0	96	.097	.114	.11/.13
4	5	5	150	0		19.5	-2.8	16.0	82	.205	.159	.22
5	5	5	300	0		74.0	6	74.0	92	.190	.179	.20
6	7	7	150	0		24.5	0	22.5	107	.259	.223	.29
7	7	7	300	0		97.5	-6	103.8	100	.123	.252	.27
8	2.5	2.5	150	102		15.0	16	10.0	97	.141	.091	.12
9	2.5	2.5	300	98		57.0	11	49.0	76	.129	.106	.11
10	2.5	2.5	150	99		18.3	22	8.5	98	.173	.077	.12
11	2.5	2.5	300	101		39.0	16	51.5	103	.090	.112	.12
12	5	5	150	99		23.3	22	20.0	97	.223	.177	.22
13	5	5	300	101	4	81.0	25	73.0	78	.187	.159	.20
14	7	7	150	100		56.5	-12	42.5	99	.537	.382	.29
17	7	7	240	104	5	73.8	-14	72.5	120	.271	.251	.28

*Amplitude

**Peak-to-Peak

This initial data has confirmed the operation of the entire system but has indicated that additional effort to improve position stability and data quality is needed.

Conclusions and Recommendations

New techniques and equipment have been developed to use the magnetic balance to produce combined spinning and coning motions of a body of revolution in a subsonic wind stream. Methods of calibration and data reduction have also been developed. Initial measurements on a spinning and coning body using these techniques have indicated that additional effort is needed to decrease data scatter, improve model position resolution and improve magnetic balance compensation for spinning and coning models.

Increased data filtering, construction of a new shielded EPS coil, and implementation of gyroscopic compensation networks for a spinning model should produce the needed improvement.

Personnel

The following professional personnel have contributed to the effort under this contract.

Professor Eugene E. Covert
Dr. Charles W. Haldeman
Mr. James B. Coffin
Mr. Charles E. Hawks

Graduate Students

Mr. Ross Bisplinghoff (M.S. June, 1976)
Mr. Omezie Ajumobi
Mr. Saghir Ahmad
Mr. Peter Dunbeck

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2. Birtwell, E. P., J. B. Coffin, E. E. Covert and C. W. Haldeman, "Reverse Magnus Force on a Magnetically-Suspended Ogive Cylinder at Subsonic Speeds", AIAA J. 16, No. 2, Feb., 1978, pp 111-116. (Manuscript revision completed under this contract). Reference 2.

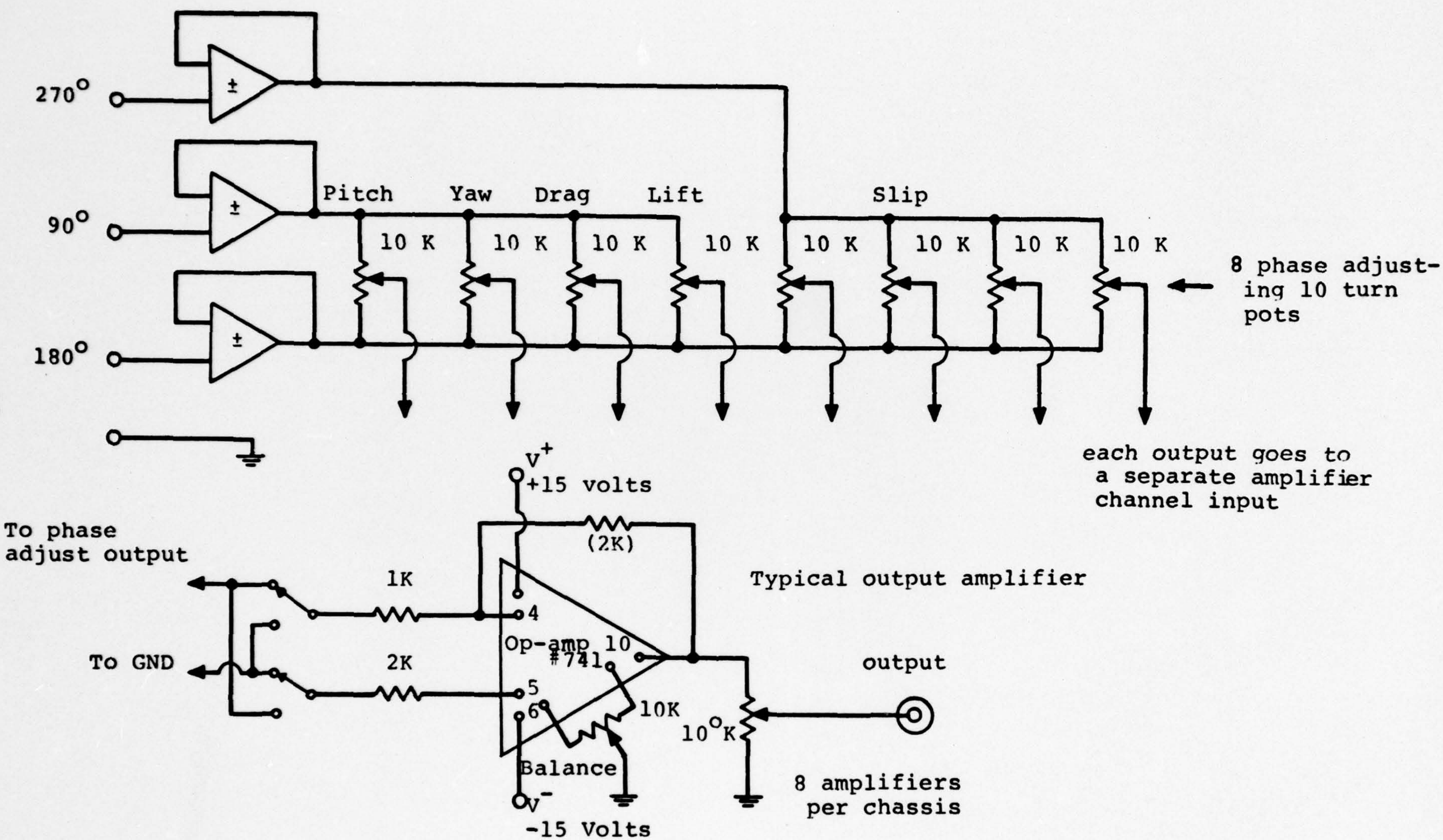

Figure 1. Phase Adjusting Chassis Schematic Diagram

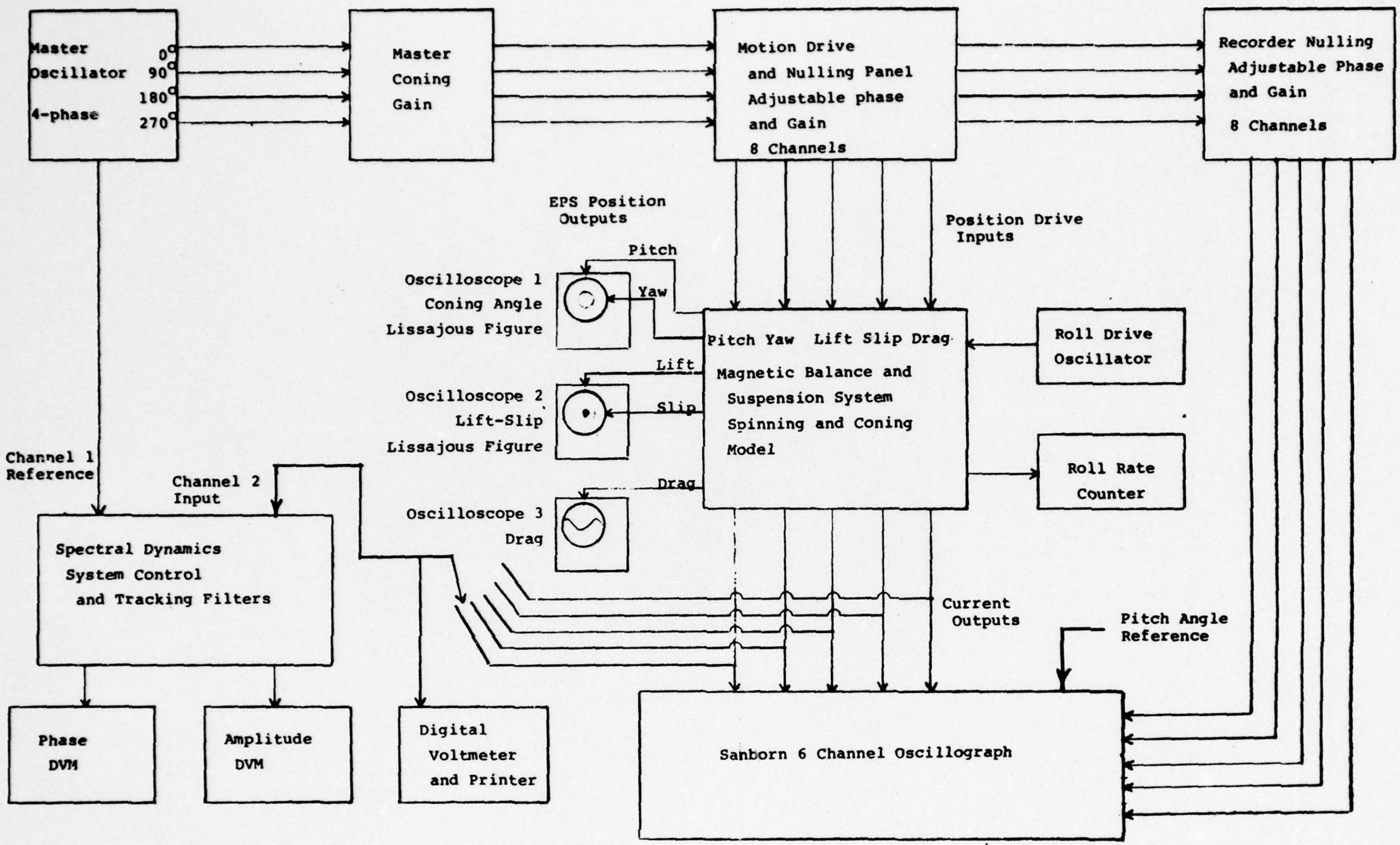

Figure 2. System used to Obtain Preliminary Data on Spinning and Coning Model

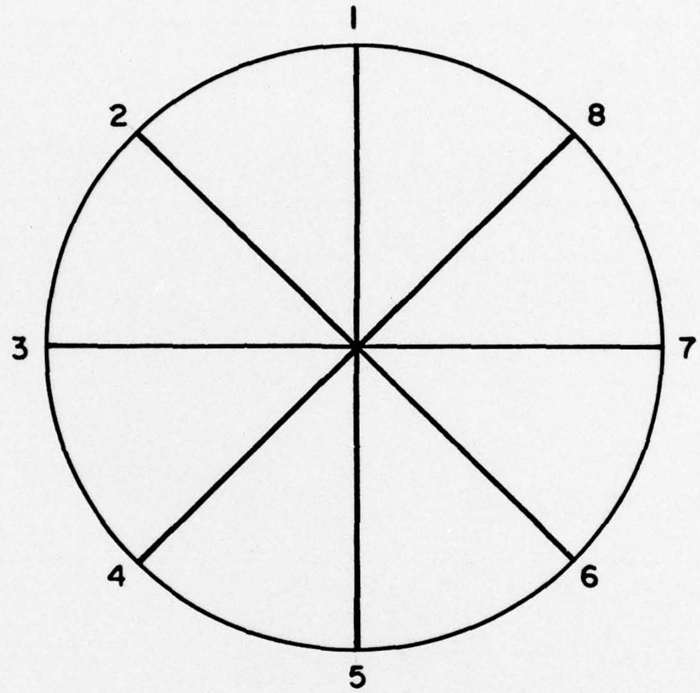

Figure 3. Static Calibration Nose Positions on an Equivalent Coning Cycle viewed from Downstream

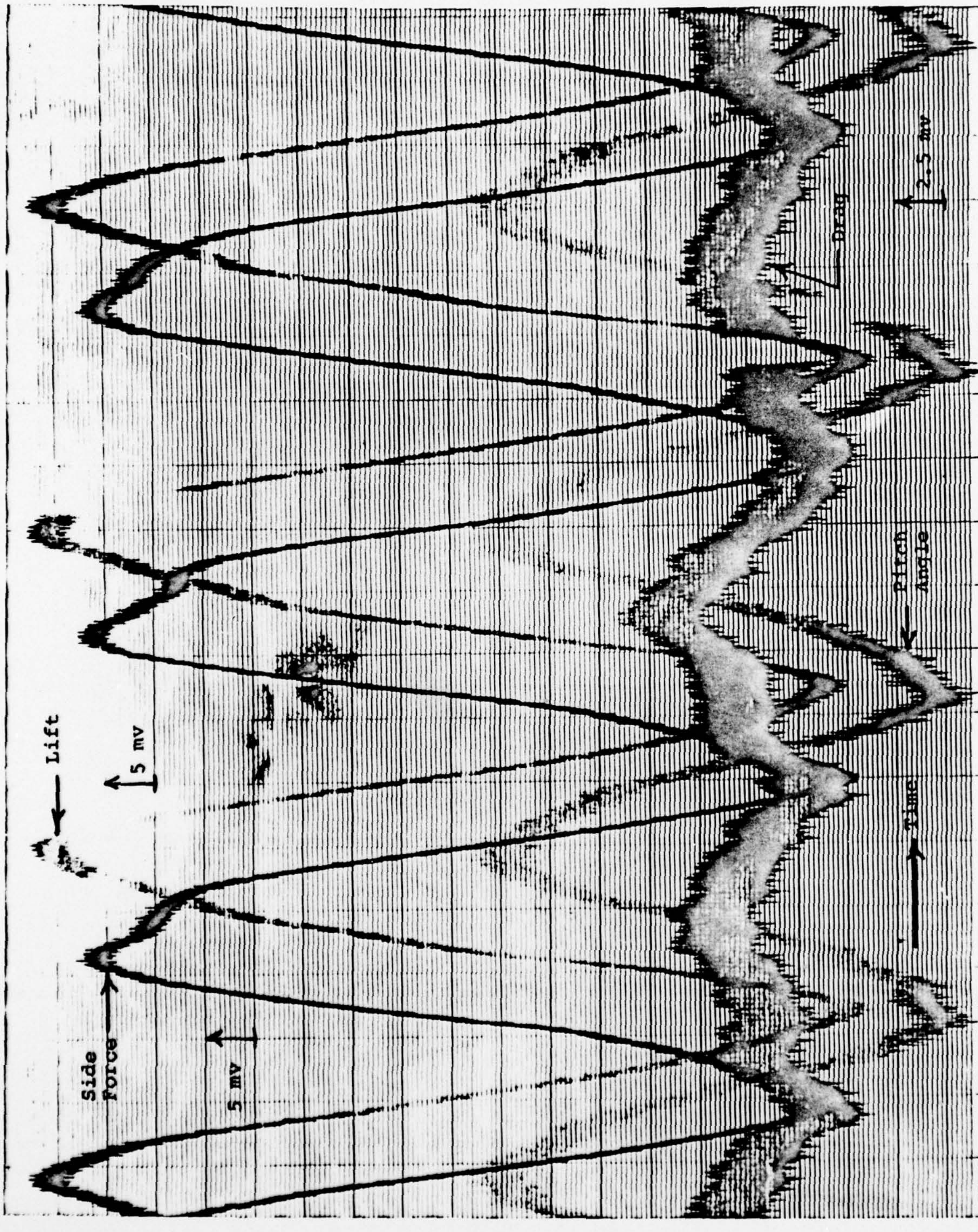

Figure 4. Run 13 Oscillograph Trace

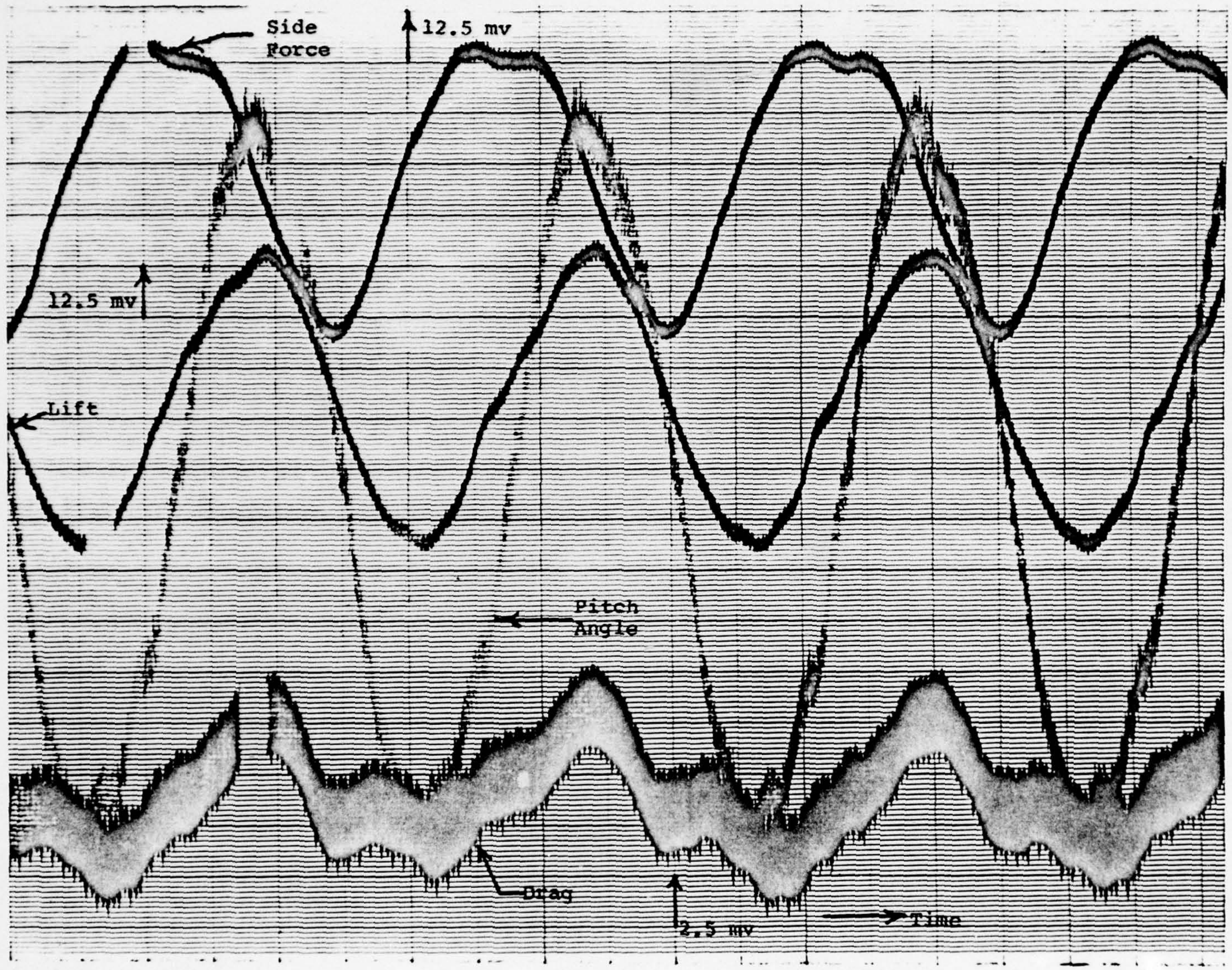

Figure 5. Run 17 Oscillograph Trace

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*This is a condensed and corrected version of the more extensive material in BRL Report CR 328, June, 1977, "Some Measurements of the Magnus Characteristics on a Magnetically Suspended 5-Caliber Ogive Cylinder" by the same authors.