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AN INEXPENSIVE ON-LINE ANALOG COMPUTER FOR A WIND TUNNEL.(U)

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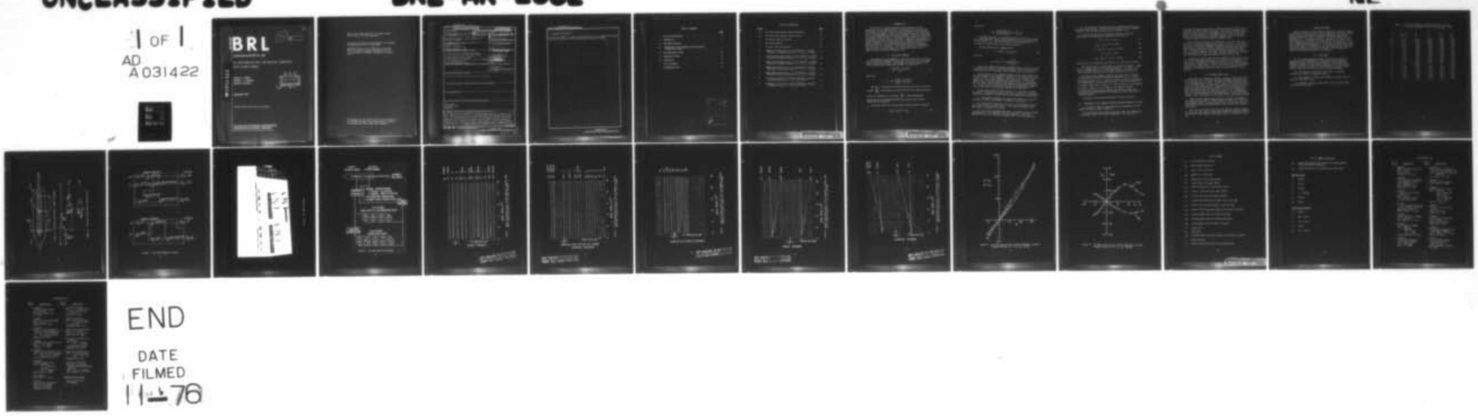

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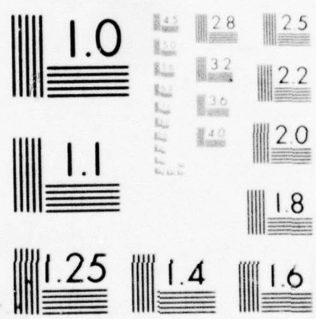

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AN INEXPENSIVE ON-LINE ANALOG COMPUTER FOR A WIND TUNNEL

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September 1976

Approved for public release; distribution unlimited.

USA BALLISTIC RESEARCH LABORATORIES
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An inexpensive analog computer has been developed which can be used for on-line data reduction of pitch and yaw strain-gage balance data during a wind tunnel test. This computer can be used with any size balance, the only restriction being that the multiplication constants of the computer must be tailored or adjusted to the calibration constants of the balance. The existing computer is constructed for use with any balance having moment bridges for measuring pitch and side forces. The computer reduces the individual bridge signals to forces,
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20. ABSTRACT (Continued):

transfers the moment to a selected moment center, and also computes the angular sting deflection due to the force and moment acting on the model.

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I. INTRODUCTION

The Ballistic Research Laboratories has developed a small, inexpensive, analog computer which, in conjunction with an existing data acquisition system, allows the direct computation and recording of the forces and moments acting on the model during wind tunnel tests. This is an improvement over the usual procedure in which the individual strain-gage bridge signals are recorded, and the reduction to forces and moments is delayed until a later time. Using the new computer, the forces and moments are recorded directly in convenient units with the moments related to a selected moment center (center of gravity). Further reduction of the data to coefficient form can be performed while the test is in progress. Data can be obtained as a function of angle of attack for polar runs or as a function of spin rate at discrete angles of attack for Magnus runs.

II. THE ANALOG COMPUTER

The principle of the computer is solid state electronic circuitry which performs the mathematical operations dictated by the strain-gage balance reduction equations. The equation for determining the force from two strain-gage bridge moment signals in Figure 1a is:

$$N = \frac{k_{RP}\ (RP) - k_{FP}\ (FP)}{L_1} \tag{1}$$

Rewriting

$$N = \left[RP - \left(\frac{k_{FP}}{k_{RP}}\right) FP\right] \left(\frac{k_{RP}}{L_1}\right)$$

The force is determined by multiplying the front pitch signal by a constant $\frac{k_{FP}}{k_{RP}}$, subtracting this from the rear pitch signal and multiplying the difference by a constant $\frac{k_{RP}}{L_1}$. These mathematical operations can be accomplished using the analog circuit (solid lines) shown in Figure 1b.

The moment about the selected moment center (center of gravity) is

$$m_{CG} = k_{FP}\ FP + N\ \ell_{CG} \tag{2}$$

Rewriting

$$m_{CG} = \left[\left(\frac{k_{RP}}{\ell_{CG}}\right)\left(\frac{k_{FP}}{k_{RP}}\right) FP + N\right] (\ell_{CG})$$

The moment transfer is accomplished by multiplying the FP signal by a second constant, adding to the computed force N, and multiplying by the constant ℓ_{CG}. These operations are accomplished by the electronic circuit (dashed lines) shown in Figure 1b.

The sting deflection is computed from:

$$\Delta\alpha = \Delta\alpha_N N + \Delta\alpha_m k_{FP} FP \quad (3)$$

Rewriting

$$\Delta\alpha = \Delta\alpha_N N + \Delta\alpha_m k_{RP}\left(\frac{k_{FP}}{k_{RP}}\right) FP$$

Again, the computation involves multiplication of the force N and the front pitch signal by constants and adding. These operations are accomplished by the electronic circuit (dotted lines) of Figure 1b.

In the case of a four component balance (two pitching moments and two yawing moments) the computer is composed of two separate electronic circuits similar to the foregoing. The pitch circuit computes the normal force, the pitching moment about the model CG (or a selected moment center), and the angular model deflection due to sting bending. The yaw circuit computes the yaw force and the yawing moment about the C.G. In the cases of interest the yaw forces and moments are sufficiently small that the yaw angular deflection is negligible.

In the actual computer circuit design, it is necessary to modify the circuits of Figure 1b slightly due to the properties of solid state amplifiers (integrated circuits) and the data acquisition system used.

(1) Each amplifier changes the sign of the signal, so it may be necessary to insert an amplifier to change the signal sign.

(2) The multiplication factor (or gain) of an amplifier must be kept within limits to minimize noise. This requires scaling of the gain factors throughout the circuit.

(3) Variation of the amplifier gains is obtained by using variable potentiometers in the feedback loop of the amplifier. With the amplifier used (I.C. #L144) gain settings from 1 to 30 are practical.

(4) The acquisition equipment used (X-Y plotters) have built in adjustable scale factors. These are used to adjust the final computed signals so that the plotter scales are in convenient units.

The above requires that the reduction equations, using the nomenclature in the definition of symbols, be written as:

$$NF = - (RP - G_1 \, FP) \, P_1 \quad (1a)$$

$$m_{CG} = (G_1 \, G_2 \, FP - G_1 \, FP) \, P_2 \quad (2a)$$

$$\Delta\alpha = [G_3 \, (RP - G_1 \, FP) + G_4 \, FP] \, P_3 \quad (3a)$$

$$FY = (G_5 \, RY - FY) \, P_4 \quad (1b)$$

$$n_{CG} = [G_6 \, FY + (G_5 \, RY - FY)] \, P_5 \quad (2b)$$

where the "G" is an amplifier gain and "P" is a plotter scale factor.

The analog circuit of these equations is shown in Figure 2. These are the circuits used in the fabricated computer. The values of all gains are determined from the strain-gage balance calibration, the sting deflection constants, and the model location on the balance.

With the present computer circuitry the *location* of the moment transfer point is restricted because the amplifier gains, G_2 and G_6, must remain within 1 to 30. If the CG is close to the front pitch and yaw bridges then G_2 and G_6 become very high. If the CG is outside of the moment centers then G_2 and $G_6 < 1$. This restriction can be relaxed by making L_1 large, or by including in the computer circuitry provisions for transferring the moment from the rear bridge, and including in the circuit means for reversing the front pitch and yaw signal polarities.

A picture of the fabricated computer is shown in Figure 3.

III. INTEGRATION OF THE COMPUTER INTO THE EXISTING ACQUISITION SYSTEM

The equipment setup for the acquisition and computation of wind tunnel test data is shown in Figure 4.

The strain-gage bridge signals from the balance are transmitted to the Magnus console for signal conditioning. This consists of filtering the strain-gage signals to remove aerodynamic tunnel noise at frequencies of about 10 Hertz and above. Additional filtering can be used, but usually results in a decrease in the response of the system making it unsatisfactory for good Magnus testing. The strain-gage signals are also amplified, to provide sufficient power to drive the X-Y plotters and to record the data on magnetic tape.

The strain-gage signals, also referred to as the raw data, are then sent to the analog computer and to the X-Y plotters. The plotters record the raw data for computing the balance constants during the pre-test balance calibration, provide a means of monitoring the condition of the balance during the test, and record the raw data during the test. The analog computer calculates the forces and moments acting on the model during the test. The output from the computer are recorded on X-Y plotters as a function of angle of attack or spin rate.

Calibration resistors, which can be momentarily placed across one leg of each strain-gage bridge, are also located in the console. Each resistor will unbalance the bridge and deflect the corresponding raw data plotter a fixed amount. It will also deflect the related computer plotters fixed amounts and in this way, after the initial calibration, the whole system operation can be checked as the wind tunnel tests proceed.

IV. THE WIND TUNNEL TESTS

Using this data acquisition system, a series of tests were run in BRL Wind Tunnel No. 1 to obtain the pitch and Magnus characteristics of a spinning projectile model. The data are recorded while the model is at a constant angle of attack and is coasting to its steady state spin rate. Spin rates away from steady state are acquired with an air turbine installed in the model. Internal forces are exerted on the model and balance while the turbine is on so that the aerodynamic forces can only be read while the model coasts. For the aerodynamic analysis, pitch and Magnus data are obtained over a spin range which includes zero or very close to zero spin rate for each angle of attack.

Samples of the computed data are shown in Figures 5 through 9. Each graph contains runs at several angles of attack and in this case each computed signal is plotted against spin. The no flow zeros are recorded and the scale factor and other pertinent data are listed on each graph.

The data in this form can be used for immediate analysis during the test, and final data in coefficient form can be obtained in minutes by performing short manual calculations (Table I and Figures 10 and 11).

V. INTERACTION TERMS

Balance interaction terms cannot be handled by the analog computer. Correcting for interactions would require additional amplifier circuits which used small gain settings, thereby complicating the scaling problem mentioned on page 8. Therefore, if balance interactions are significant it is recommended that this computer not be used, unless some other means can be found to account for the interactions. In the case of Magnus measurements, we have found that the normal force interaction terms can be eliminated by: (1) rolling the balance until the interaction terms are minimized and (2) subtracting the zero spin loads from the spin loads at each angle of attack. This technique will reduce the interaction errors to a few percent.

VI. CONCLUSIONS

(1) The analog computer provides an inexpensive method of obtaining on-line computation of wind tunnel pitch and yaw data. Immediate analysis of these data are possible, thereby making it possible to change the test program direction as the tests proceed. Further reduction of the data to coefficient form requires little effort and can be done while the tests are being performed.

(2) The computer can be used with balances of different capacities by varying the amplifier gains.

(3) The computer is compact and portable and can be used for tests at other facilities.

(4) Computers, similarly constructed, can be used with other data acquisition systems.

Table I. 6 Caliber ANSR With a Straight Triangular Boattail, $M = 3.0$, $R_d = 974{,}000$, $d = 5.72$ cm, $(pd/V)_{max} = .2833$

α_i	$\alpha_i + \Delta\alpha$	C_N	C_m	C_{N_p}	C_{m_p}
15	16.21	1.2772	1.2037	-.0808	.0328
12.5	13.49	1.0041	1.0080	-.0933	.0501
10	10.78	.7399	.8220	-.1026	.0708
7.5	8.09	.5109	.6361	-.0933	.0777
5	5.39	.3193	.4306	-.0653	.0622
4	4.32	.2532	.3425	-.0560	.0466
3	3.23	.1872	.2593	-.0466	.0449
2	2.16	.1211	.1713	-.0311	.0311
1	1.08	+ .0573	+ .0832	-.0187	.0173
0	0	- .0044	0	0	.0035
-1	- 1.08	- .0661	- .0881	.0218	-.0121
-2	- 2.15	- .1321	- .1223	.0311	-.0294
-3	- 3.23	- .1960	- .2544	.0435	-.0432
-4	- 4.31	- .2598	- .3327	.0591	-.0518
-5	- 5.39	- .3281	- .4208	.0653	-.0604

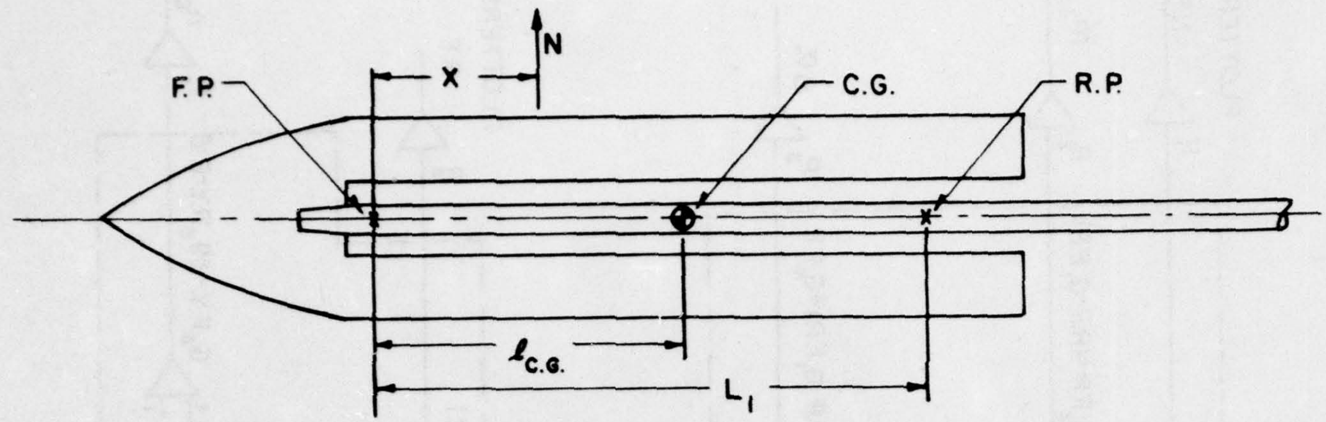

Figure 1a. The Strain Gage Balance---Model Arrangement

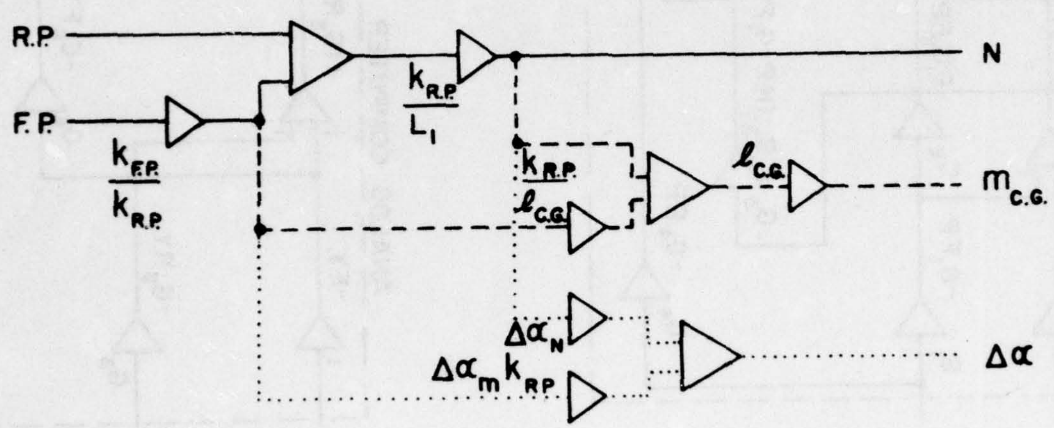

Figure 1b. The Strain Gage Balance---Analog Circuit

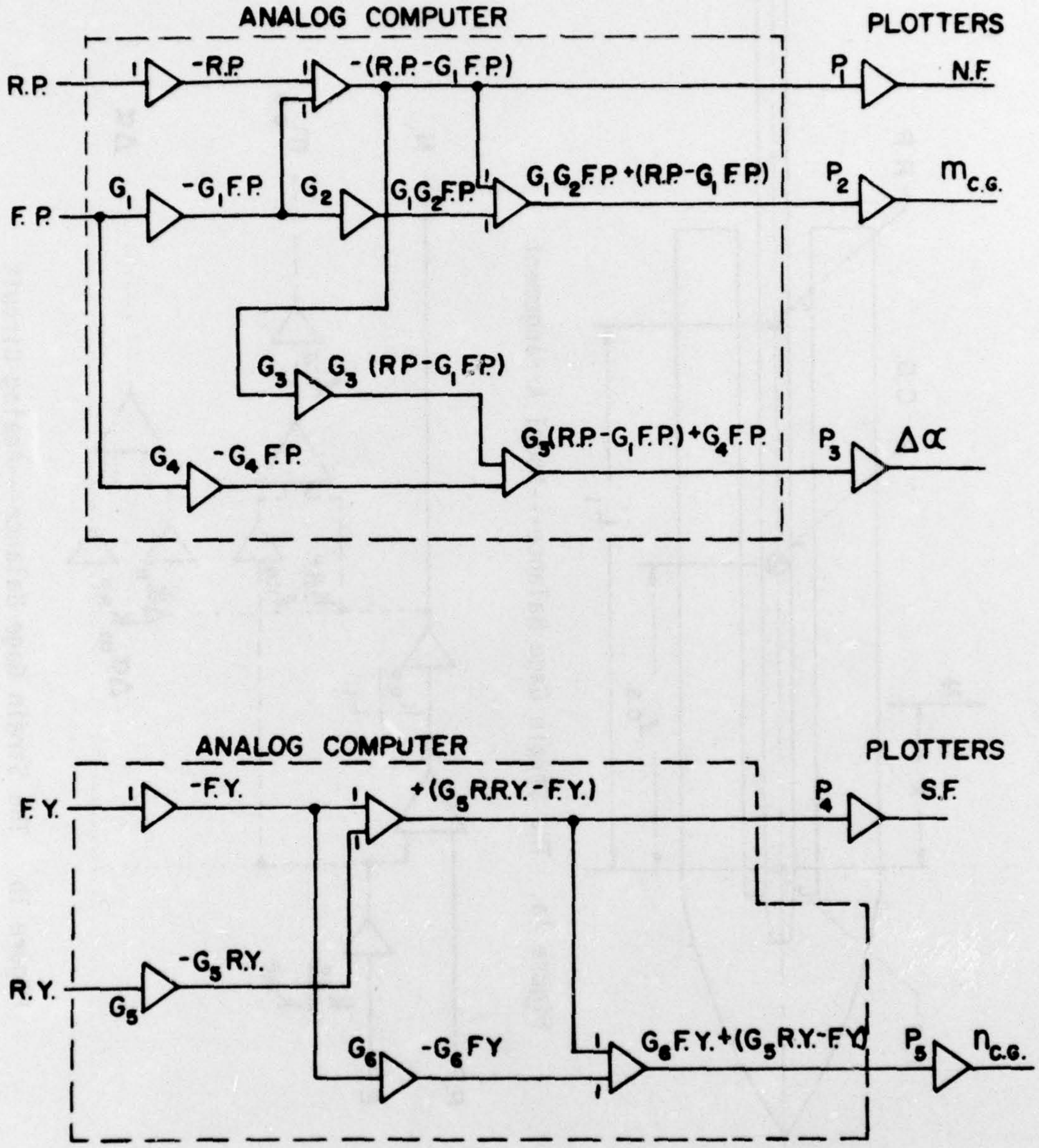

Figure 2. The Analog Computer Circuits

Figure 3. The Analog Computer

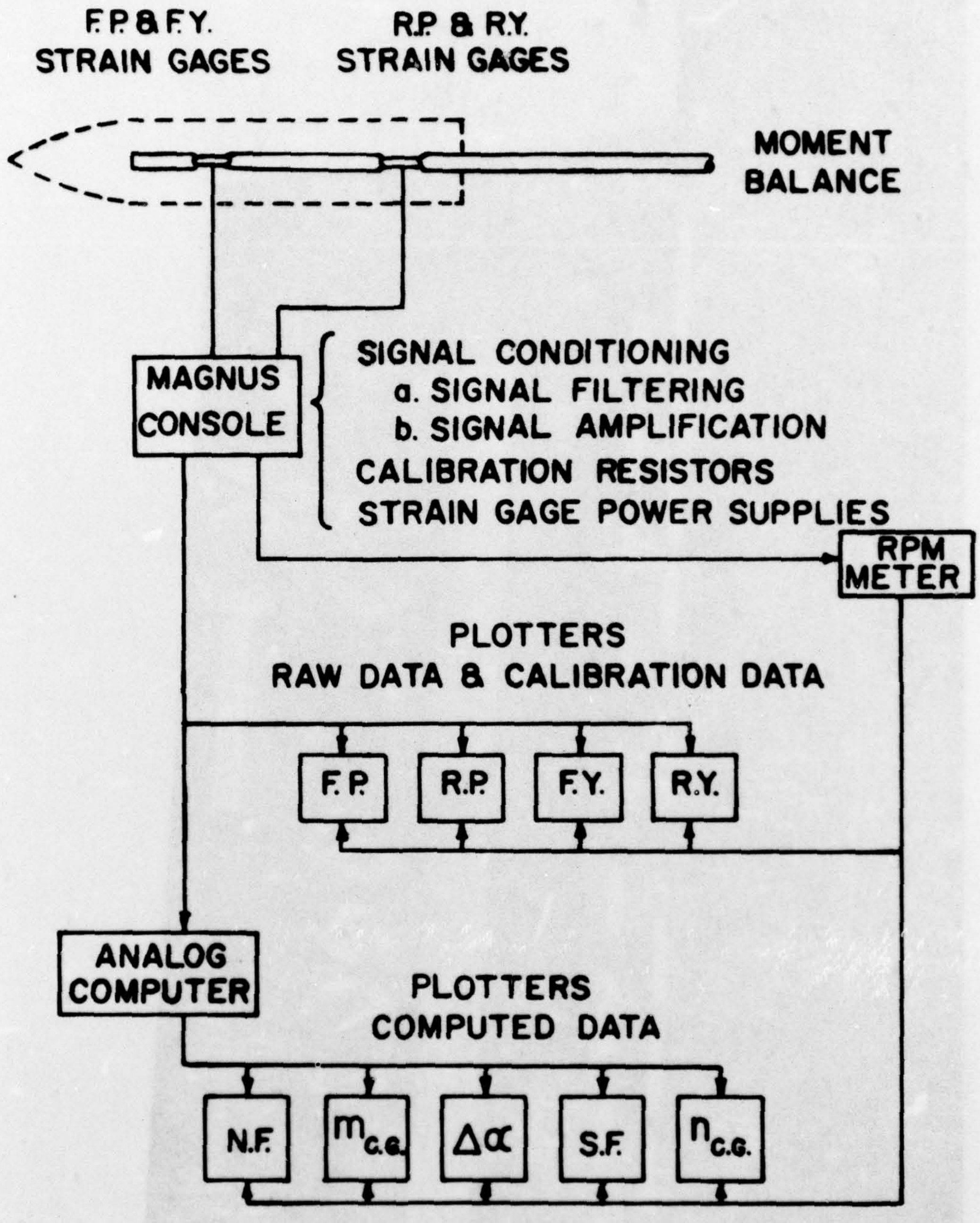

Figure 4. The Data Acquisition System

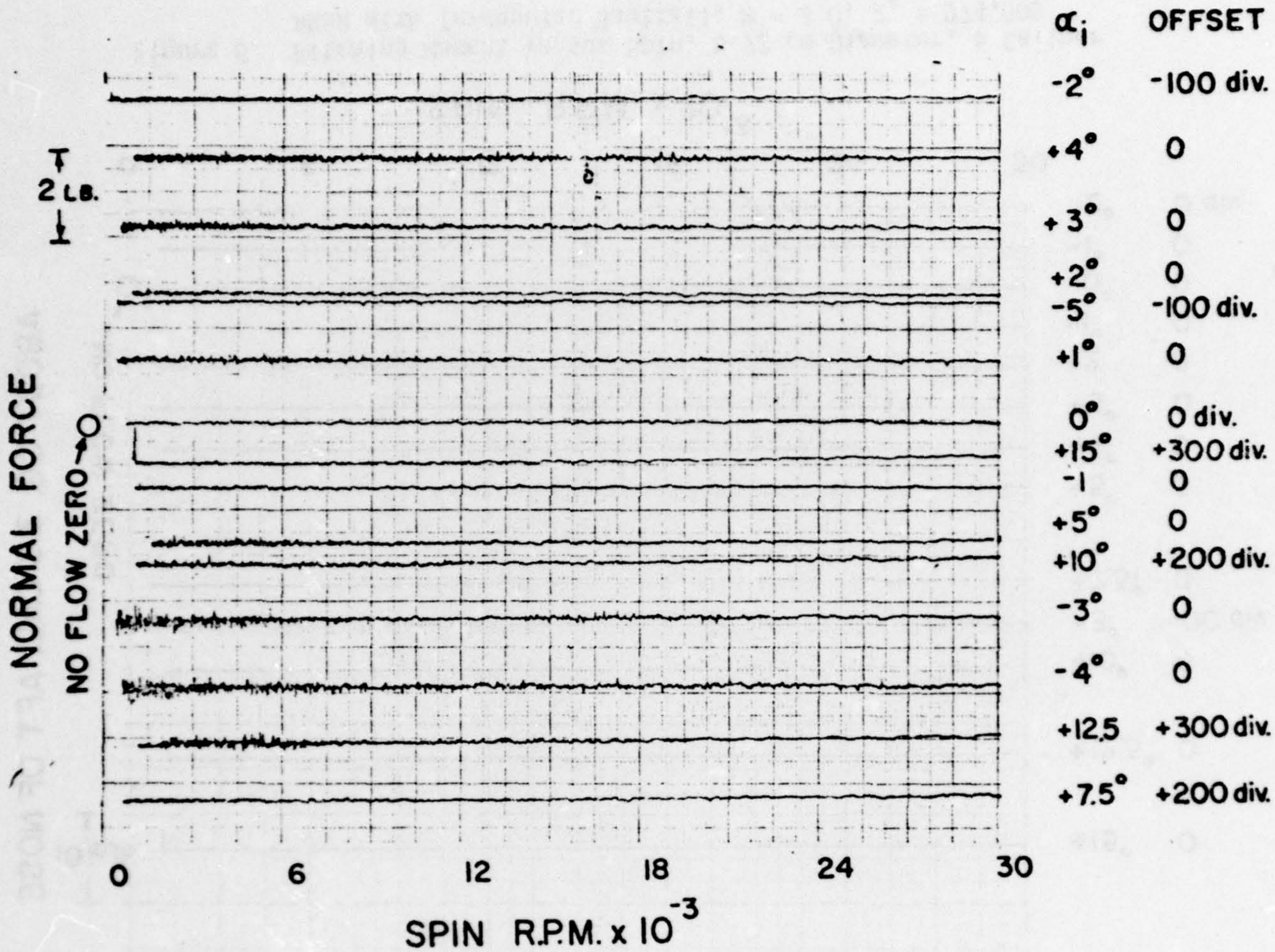

Figure 5. Normal Force Versus Spin, 5.72cm Diameter, 6 Caliber ANSR With Triangular Boattail, $M = 3.0$, $R_d = 974,000$

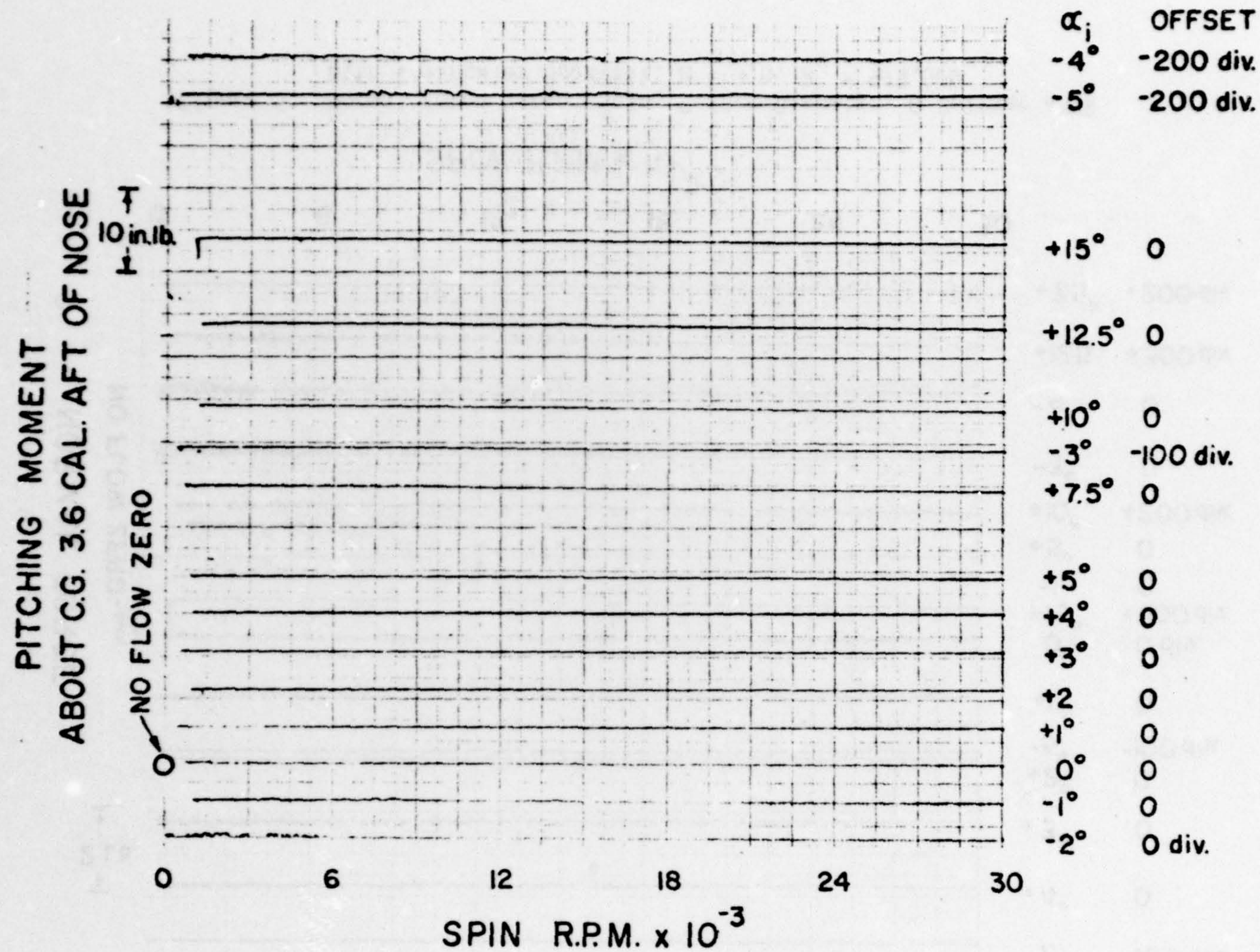

Figure 6. Pitching Moment Versus Spin, 5.72 cm Diameter, 6 Caliber ANSR With Triangular Boattail, $M = 3.0$, $R_d = 974,000$

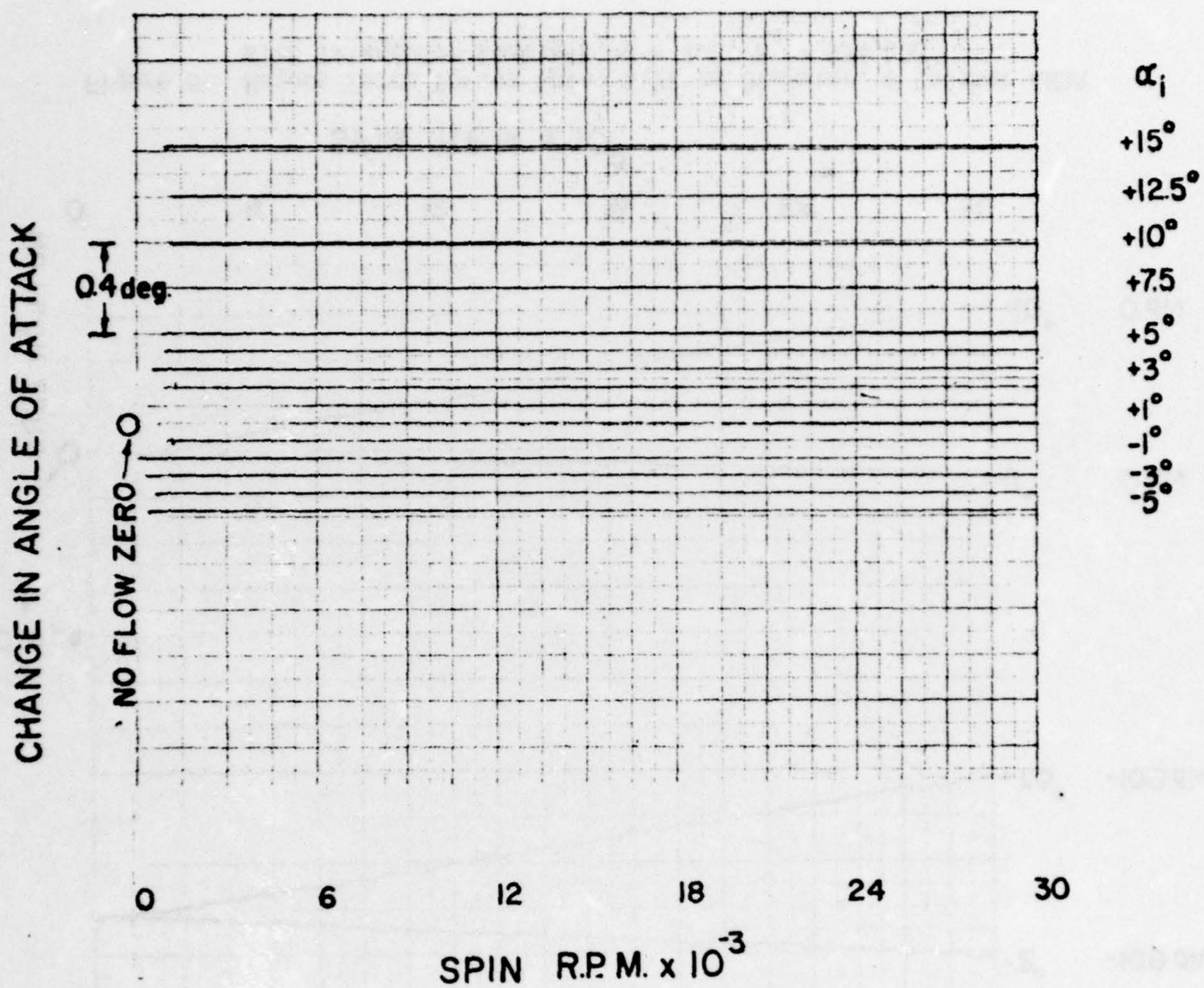

Figure 7. Angle of Attack Versus Spin, 5.72 cm Diameter, 6 Caliber ANSR With Triangular Boattail, M = 3.0, R_d = 974,000

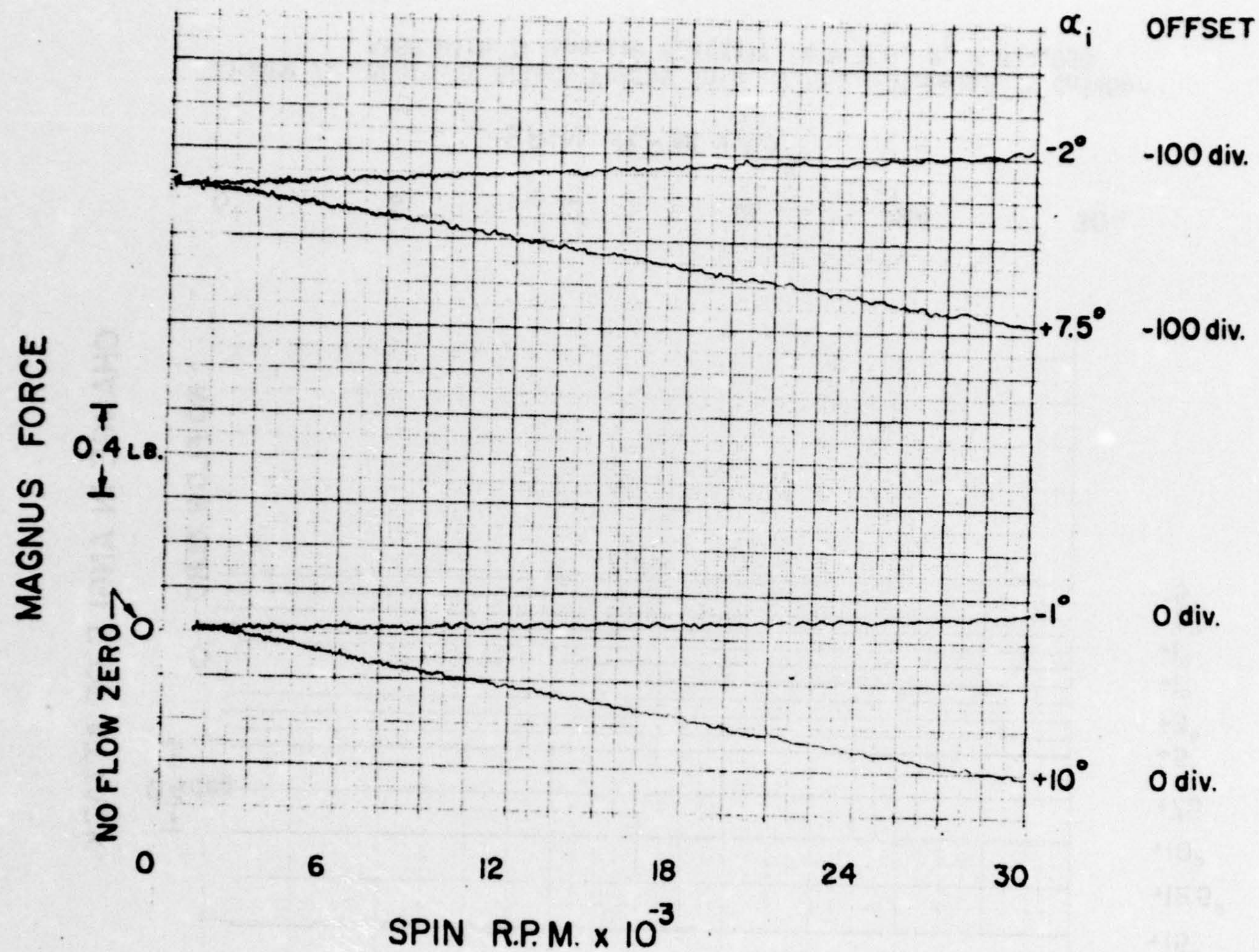

Figure 8. Magnus Force Versus Spin, 5.72 cm Diameter, 6 Caliber ANSR With Triangular Boattail, M = 3.0, R_d = 974,000

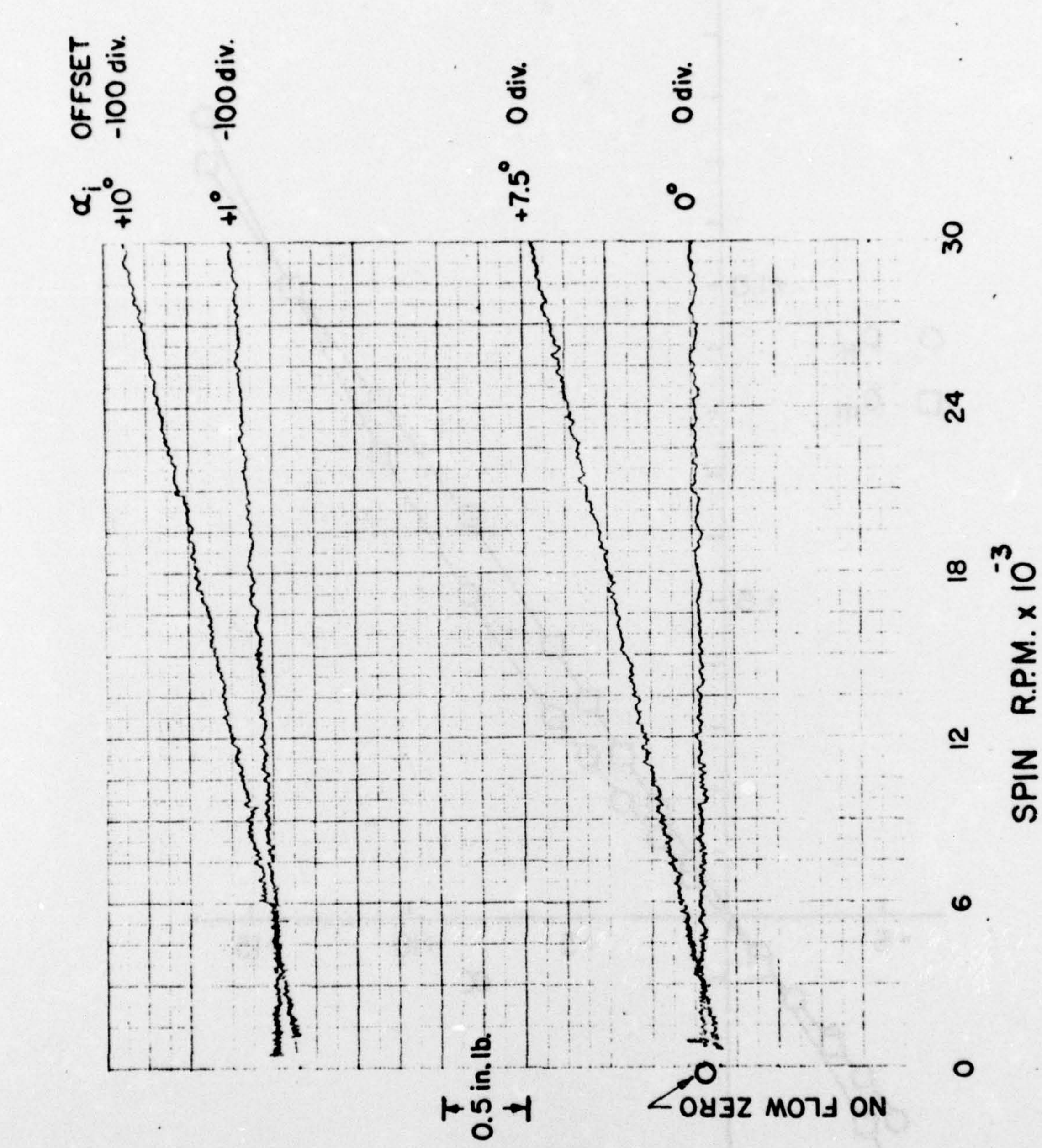

Figure 9. Magnus Moment Versus Spin, 5.72 cm Diameter, 6 Caliber ANSR With Triangular Boattail, M = 3.0, R_d = 974,000

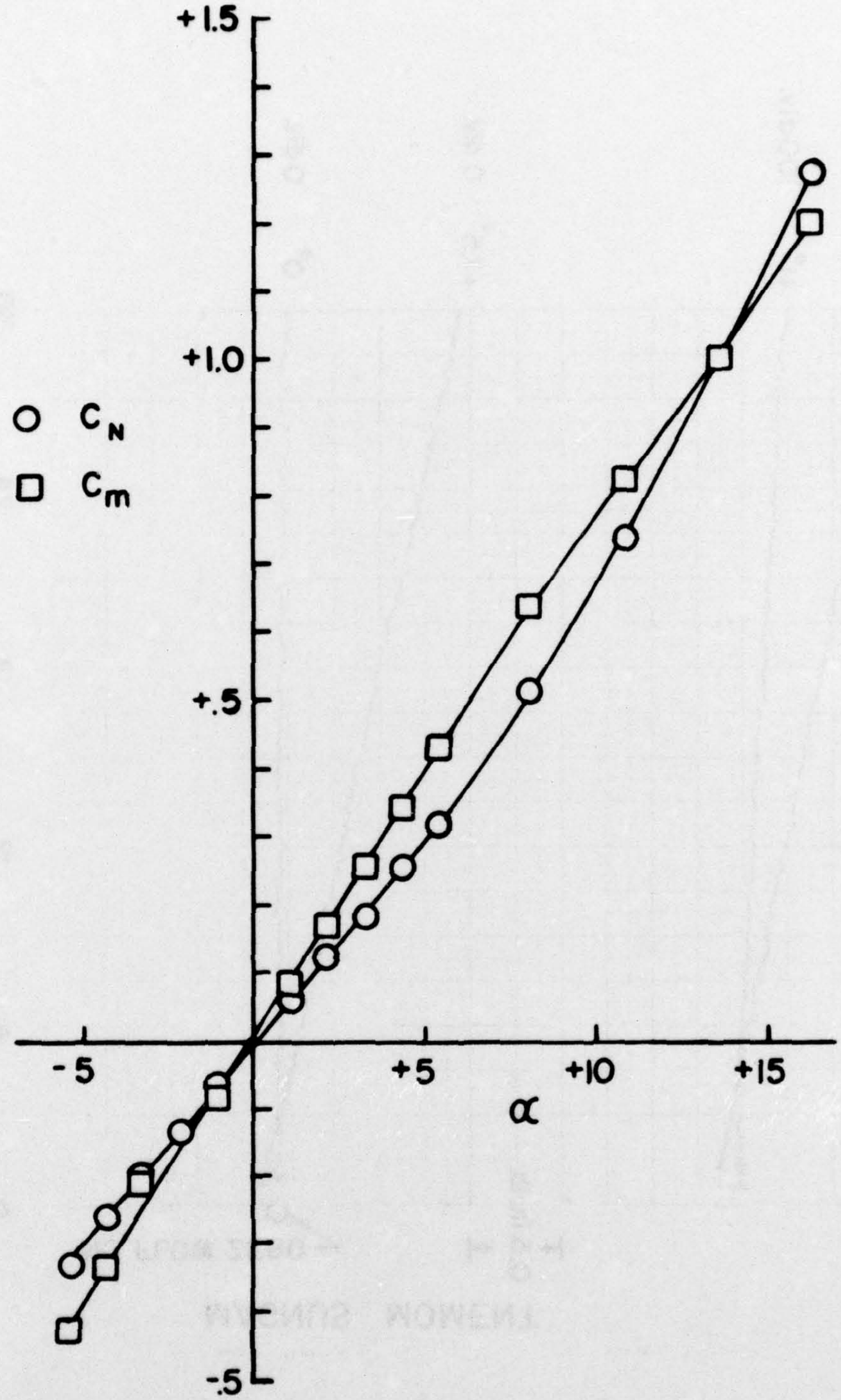

Figure 10. The Pitch Data for the 6 Caliber ANSR With a Straight Triangular Boattail, M = 3.0, R_d = 974,000

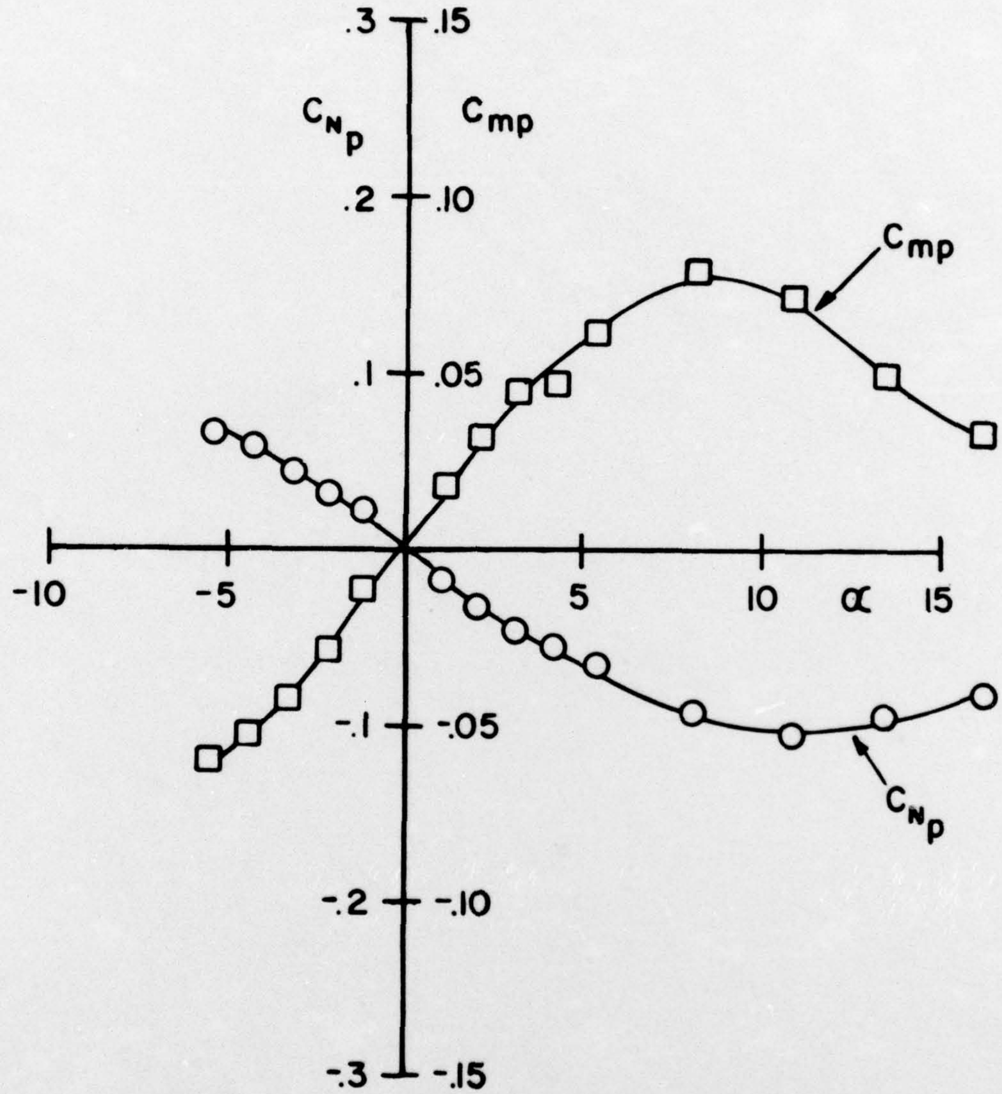

Figure 11. The Magnus Data for the 6 Caliber ANSR With a Straight Triangular Boattail, M = 3.0, R_d = 974,000

LIST OF SYMBOLS

C_m	pitching moment coefficient
C_{mp}	Magnus moment coefficient
C_N	normal force coefficient
C_{NP}	Magnus force coefficient
FP	forward pitch strain-gage reading
FY	forward yaw strain-gage reading
k_{FP}	balance forward pitch strain-gage constant
k_{FY}	balance forward yaw strain-gage constant
k_{RP}	balance rear pitch strain-gage constant
L_1	distance from forward pitch gage to rear pitch gage
L_2	distance from forward yaw gage to rear yaw gage
ℓ_{CG}	distance from forward pitch gage to the center of gravity
m_{CG}	pitching moment about the center of gravity
m_{FP}	pitching moment about the forward pitch gage
n_{CG}	yawing moment about the center of gravity
NF	normal force
SF	side force
Y_{CG}	distance from the forward yaw gage to the center of gravity
α	angle of attack
$\Delta\alpha$	angle-of-attack correction for sting deflection

LIST OF SYMBOLS (Continued)

$\Delta\alpha_m$ angular deflection of the sting due to pitching moment about the forward pitch gage

$\Delta\alpha_N$ angular deflection of the sting due to normal force

Amplifier Gains

G_1 k_{FP}/k_{RP}

G_2 L_1/ℓ_{CG}

G_3 $\Delta\alpha_N/\Delta\alpha_m$

G_4 $L_1 \cdot k_{FP}/k_{RP}$

G_5 k_{RY}/k_{FY}

G_6 L_2/Y_{CG}

Plotter Scale Factors

P_1 k_{RP}/L_1

P_2 $k_{RP} \cdot \ell_{CG}/L_1$

P_3 $\Delta\alpha_m \cdot k_{RP}/L_1$

P_4 k_{FY}/L_2

P_5 $k_{FY} \cdot Y_{CG}/L_2$

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