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MARCH 1963

THE MAGNUS FORCE ON A FINNED BODY

Anders S. Platou

RDT & E Project No. 1A222901A201

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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ASPlatou/gek
Aberdeen Proving Ground, Md.
March 1963

THE MAGNUS FORCE ON A FINNED BODY

ABSTRACT

The effect of spin on the aerodynamic forces generated on a slowly spinning finned projectile is analyzed. Experiments in the BRL wind tunnels, which substantiate the analysis, are described and presented. It is seen that the Magnus forces and moments are as large as those existing on a rapidly spinning nonfinned projectile where these forces are known to have an influence on accuracy and stability.

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TABLE OF SYMBOLS

a	speed of sound
d	model diameter
r	distance from center of rotation (body centerline)
M	Mach number $= \frac{U}{a}$
P_o	stagnation pressure
q	dynamic pressure $= \frac{1}{2} \rho U^2$
Re	Reynolds number $= \frac{\rho U d}{\mu}$
T_o	stagnation temperature
U	test section air velocity
α	angle of attack (positive α is nose up)
ρ	test section air density
μ	test section air viscosity
ω	spin rate of model (plus is clockwise looking upstream)
ν	$\frac{\omega d}{2U}$
C_f	Magnus force coefficient $= \dfrac{f}{\frac{1}{2} \rho U^2 \frac{\pi d^2}{4} \frac{\omega d}{2U}}$ (plus is to left looking upstream)
C_T	Magnus moment coefficient $= \dfrac{T}{\frac{1}{2} \rho U^2 \frac{\pi d^3}{4} \frac{\omega d}{2U}}$ (plus is plus force ahead of moment center)
C.P.	Magnus force center of pressure location from base in calibers

INTRODUCTION

In many cases of finned projectile flights it has become necessary to spin the projectile during flight in order to overcome the manufacturing asymmetries of the body and fins. This tends to nullify the effect of fin asymmetries; however, the spin produces a Magnus force which may have a significant bearing on the trajectory. The bare body Magnus force has been explained in previous reports;[1-9] however, the influence of spin on the fins is a phenomena which has never been studied. As will be seen below, the Magnus force developed on rotating fins is due to an entirely different mechanism than that responsible for the Magnus force on a body.

When a rectangular flat plate is rotated, at a rate ω, about a line parallel to one of its sides, and parallel to a uniform supersonic air stream U, figure 1, the lift coefficient is equal to[10]

$$C_L = \frac{4\alpha}{\sqrt{M^2-1}}$$

Here M is the free stream Mach number and α is the angle of attack created by the rotation of the flat plate. The angle of attack varies uniformly along the span of the flat plate and has its largest value at the extreme outboard section. It can be determined from

$$\alpha = \frac{\omega r}{U}$$

When there is a series of flat plates aligned as the fins on a projectile the lift force on each fin contributes toward a torque about the centerline of rotation (the body axis) which tends to retard the rotation. The lift on each fin is perpendicular to the fin surface and at zero angle of attack the lift forces on opposite fins cancel one another leaving only the torque. When the projectile is at other than zero angle of attack the body interference on the fins is such that the lift force on the leeward fin is reduced, thereby leaving an unbalanced force. This force acts perpendicular to the angle of attack plane and from figure 2 it can be seen that this force acts in the opposite direction to the body Magnus force. It is therefore possible, depending on the body and fin configuration to obtain either a positive, zero, or negative Magnus force on the projectile. The magnitude of the Magnus force in this case can only be determined by finding the body interference from experiment.

Even though the body and fin Magnus forces oppose one another, they do not have the same centers of pressure. As a result a moment couple, independent of the center of gravity, is created which is equal to the lesser of the two forces multiplied by the distance between them, figure 2. The total Magnus moment about the projectile center of gravity will be the sum of the couple plus the moment due to the unbalanced Magnus force.

In order to verify the above ideas and to determine the body interference a fin configuration, figure 3, has been tested in a supersonic wind tunnel. The configuration is one where the fin span is equal to the body major diameter. Also, the fins have been end-plated, for other investigations(11) show this increases the fin effectiveness in longitudinal stability. Both a spike nose and a conical nose have been included, for both noses are used on mass produced configurations of this type.(12) The noses produce radically different flows to their rear and it is expected that the fin Magnus forces will in turn be different. The tests cover the Mach number range 1.75 to 4.00, for this is the normal operating range of these configurations.

It is also interesting to note here that when a body plus canted fins combination is considered, the configuration will free spin at some rate ω where the resultant rolling moment on each fin is zero. However, due to

$$\alpha = \frac{\omega r}{U} ,$$

the lift force on various fin sections is not everywhere zero. Negative forces (a force tending to increase spin) will exist on the inboard wing sections and positive forces will exist on the outboard wing sections, figure 4. For zero rolling moment the positive and negative moments must be equal such that $\int r dL = 0$. If now this configuration is placed at a small angle of attack, each fin as it rotates to the lee side of the body will lose portions of its inboard lift distribution, thereby providing a means of producing a positive Magnus force. As the angle of attack is increased further, the lee fin begins to lose its outboard lift distribution so that the Magnus force would then decrease toward zero. Through this mechanism it is possible to predict a nonlinear Magnus force on a free spinning finned missile.

MODELS AND INSTRUMENTATION

The models have been designed along the same lines as those used in references 1 and 2. The model or outside surface of each configuration is the revolving portion of an air-driven motor which is mounted on the outer races of precision ball bearings. The inner races of the bearings are mounted on a stationary cylinder which in turn is mounted on the upstream end of the four-component s.g. balance (2 pitch and 2 yawing moments) and supporting strut. Spin rate indication is obtained from an electrical signal generated in a stationary coil by a moving magnet (and magnetic field) mounted in the spinning portion of the model.

Two air motors had to be used for spinning the models. The first is used only with the bare body configuration and is the same as used in references 1 and 2 except smaller. Its smaller size was necessitated by the physical space inside the model and also by the choking of the exhaust air as it passed through the small exit area at the tail of the model. This choking effect forced a reduction in the nozzle throat area and the nozzle supply pressure, thereby reducing the available power. Fortunately it is necessary to spin these models only to 5000 rpm so that sufficient power is still available for the bare body model. The finned models require more power than is available so we had to resort to a jet of high pressure air directed onto the model fins. The air jet is directed onto the fins to accelerate the model and then retracted to a downstream position so that no external forces from the nozzle act on the model while the balance is read. With both air motors data can be obtained only during the coasting period.

The readout equipment for the strain gage signals has been revised, from that used to obtain the body data, so that automatic data recording is now possible on all four channels. The spin rate signal is changed from a variable frequency signal to a D.C. signal and placed on the abscissa of four x-y plotters. Each of the strain gage bridge signals in turn are put on the ordinate axes of the x-y plotters, thereby giving continuous recordings of the aerodynamic moments during the coasting period of the model. The pitching moment signals are fed directly to plotters; however, the yaw signals must be filtered in order to eliminate oscillatory signals induced by tunnel turbulence and model oscillations. The balance is much weaker in the yaw direction than in the pitch direction and the tunnel turbulence causes some oscillations in the yaw direction. The spike nose configurations,[12] which produce an aerodynamic oscillation of their own, excite balance oscillations to a larger degree than the cone nose configurations.

In reading the moment data from the x-y plots it is necessary to extrapolate from 500 rpm to zero. The electronic black box which converts the spin signal to a D.C. signal will not record properly between 500 rpm and zero. Also, the variation of fin normal force with the model roll angle makes it impossible to obtain an average moment reading at zero spin. The data between 4000 rpm and 500 rpm are linear so that a linear extrapolation to zero spin is reasonable.

The extrapolation is not necessary on the bare body configurations for there is no variation of normal force with roll position. Even though the spin signal still does not record properly below 500 rpm, the zero spin moment is accurate and the 500 rpm gap can be interpolated.

TEST PROCEDURE AND RESULTS

The tests on these models have been run in the BRL Tunnel No. 1, with a few check runs being made in Tunnel No. 3. Both tunnels cover the same Mach number range and can be used alternately; however, Tunnel No. 1 is usually preferred, for the flow uniformity is slightly better.[13] Data were obtained in the angle of attack range of $\pm 5^{\circ}$ at 1° increments using a nearly constant Reynolds number condition.

The data obtained during these tests agree very well with the ideas expressed in the introduction (Figs. 5, 6, 7, and 8). The Magnus force on the fins acts in the opposite direction from that on the body, and with the fin configuration tested the fin force is in general larger than the body force. The moment couple exists, as is evidenced by the rearward center of pressure location. The couple, plus the moment due to the unbalanced fin force, places the effective center of pressure up to several calibers behind the base of the model. From these data we find that the Magnus moments on slowly spinning finned configurations are as large as those existing on rapidly spinning bodies of revolution.

The original plan in conducting the wind tunnel experiments was to test several configurations so that possible ways and means of varying the Magnus force could be studied. However, the tests on the first two configurations (the spike nose and the cone nose) show that even though the data are sufficiently accurate to prove our original ideas, they are not sufficiently accurate to show variations due to Reynolds number, Mach number, and configuration differences. Estimates of the data accuracy have been made by comparing data at positive and negative angles of attack. The data should be symmetric about zero angle of attack; however, inspection of the data shows differences of the order of 25%.

The reason for the inaccuracies is the inability to obtain the desired sensitivity in the yawing moment gages. The gage sections must be designed to withstand the normal force stresses as well as the Magnus force stresses, and since the Magnus force is less than 5% of the normal force, the normal force controls the gage section dimensions and hence the sensitivity. Also, the gage section dimensions determine the natural frequency of the strain beam and model and it is necessary to keep the frequencies sufficiently high to prevent resonance with the tunnel turbulence frequencies. With the present system, enough of the turbulence enters the balance yaw signals to require electronic filters before recording the signals on the x-y plotters.

Another source of inaccuracy is the location of the two yawing moment gages. These are located inside the model (2.75 and 4.25 cal forward of the base) close to the body alone Magnus force center of pressure. However, the finned body Magnus center of pressure is located in general behind the model base, thereby reducing the accuracy of the data reduction. This is being corrected by locating a third yawing moment gage downstream of the fins. The sensitivity of the yaw signal is also to be increased by using semi-conductor gages rather than the wire gages. Temperature drifts, which are a disadvantage of the semi-conductor gages, may not be bothersome for only relative readings taken a few minutes apart are required. If the semi-conductor gages are satisfactory the program will be continued using the new gages.

CONCLUSIONS

Analysis of the flow over a slowly spinning finned projectile brings forth the following results:

1. The wake created by the body of a spinning finned-body configuration interferes with the lift force on the rotating fins in such a manner that a side force results.

2. The side force on the fins of a configuration which is not in free spin is opposite in direction to the body Magnus force so that the resulting side force can be in either direction or zero.

3. The side force on the fins of a configuration which is in free spin will be in the same direction as the body Magnus force at low angles of attack. At higher angles of attack the Magnus force will decrease toward zero.

4. The body Magnus force and the fin side force usually do not have the same centers of pressure. Therefore a moment exists, which is independent of the center of gravity, and is equal to the lesser of the two forces multiplied by the distance between them. This moment, plus the moment due to the unbalanced force, can move the center of pressure outside of the projectile length.

5. The side forces and moments on a slowly spinning finned projectile can be as large as those existing on a rapidly spinning nonfinned projectile.

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.REFERENCES

1. Platou, A. S., and Sternberg, J. The Magnus Characteristics of a 30mm Aircraft Bullet. BRL R-994, February 1957.

2. Platou, A. S. The Magnus Force on a Short Body at Supersonic Speeds. BRL R-1062, March 1959.

3. Platou, A. S. The Magnus Force on a Rotating Cylinder in Transonic Crossflows. BRL R-1150, September 1961.

4. Martin, John C. On Magnus Effects Caused by the Boundary Layer Displacement Thickness on Bodies of Revolution at Small Angles of Attack. BRL R-870, Revised. June 1955.

5. Kelly, Howard R. An Analytical Method for Predicting the Magnus Forces and Moments on Spinning Projectiles. NAVORD Tech Memo 1634, August 1954.

6. Kelly, Howard R., and Thacker, G. Robert. The Effect of High Spin on the Magnus Force on a Cylinder at Small Angles of Attack. NAVORD Rpt. 5036, February 1956.

7. Luchuk, W., and Sparks, W. Wind Tunnel Magnus Characteristics of the 7 Cal A.N. Spinner Rocket. NAVORD Rpt. 3813, September 1954.

8. Murphy, C. H. The Measurement of Non-Linear Forces and Moments by Means of Free Flight Tests. BRL R-974, February 1956.

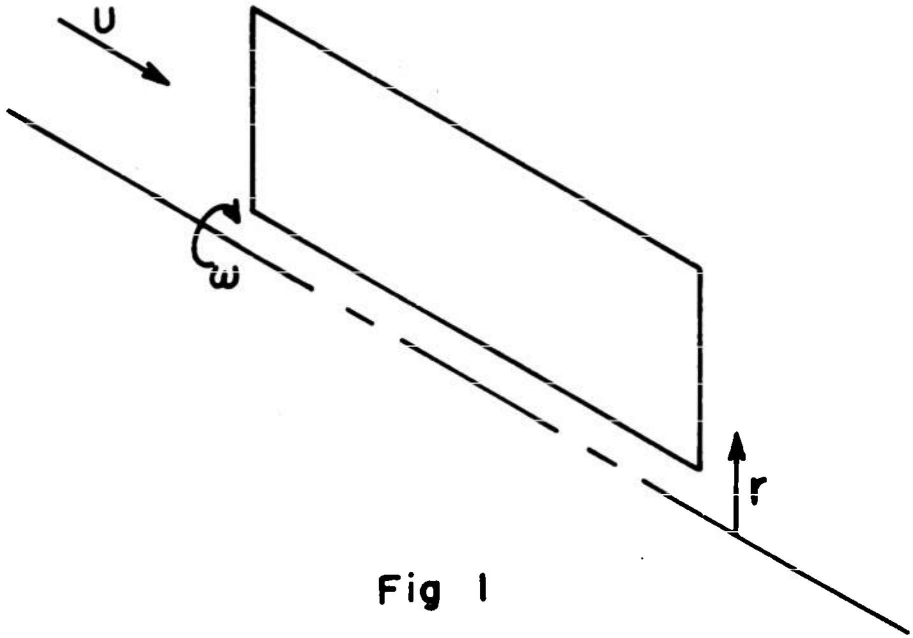
9. Hall, R. T. The Lift and Drag on a Rotating Cylinder in Supersonic Crossflow. NAVORD Rpt. 6039, February 1960.

10. Liepmann, H., and Puckett, A. <u>Aerodynamics of a Compressible Fluid: p. 146</u>. New York: John Wiley and Sons, Inc., 1947.

11. Platou, A. S. The Effects of High Stability Noses on Finned Configurations. BRL TN-707, June 1952.

12. Platou, A. S. Body Nose Shapes for Obtaining High Static Stability. BRL M-593, February 1952.

13. McMullen, J. C. Wind Tunnel Testing Facilities at the Ballistic Research Laboratories. BRL M-1292, July 1960.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ω
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Fig 1

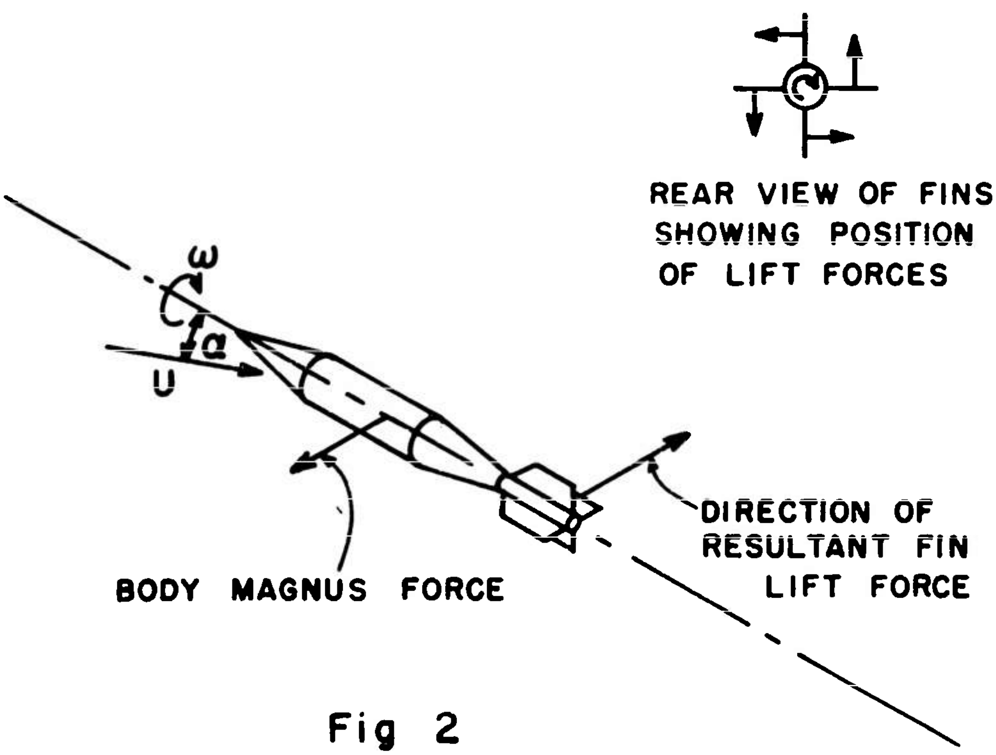
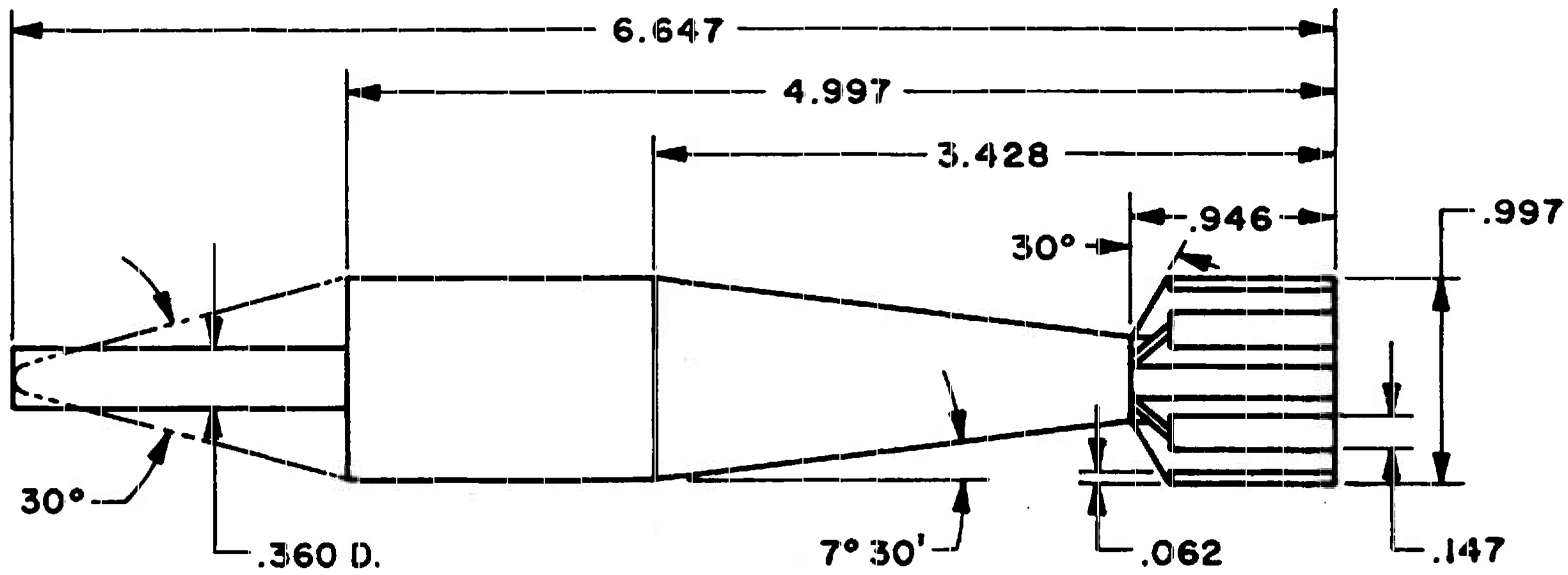

REAR VIEW OF FINS
SHOWING POSITION
OF LIFT FORCES
ω
a
U
BODY MAGNUS FORCE
DIRECTION OF
RESULTANT FIN
LIFT FORCE

Fig 2

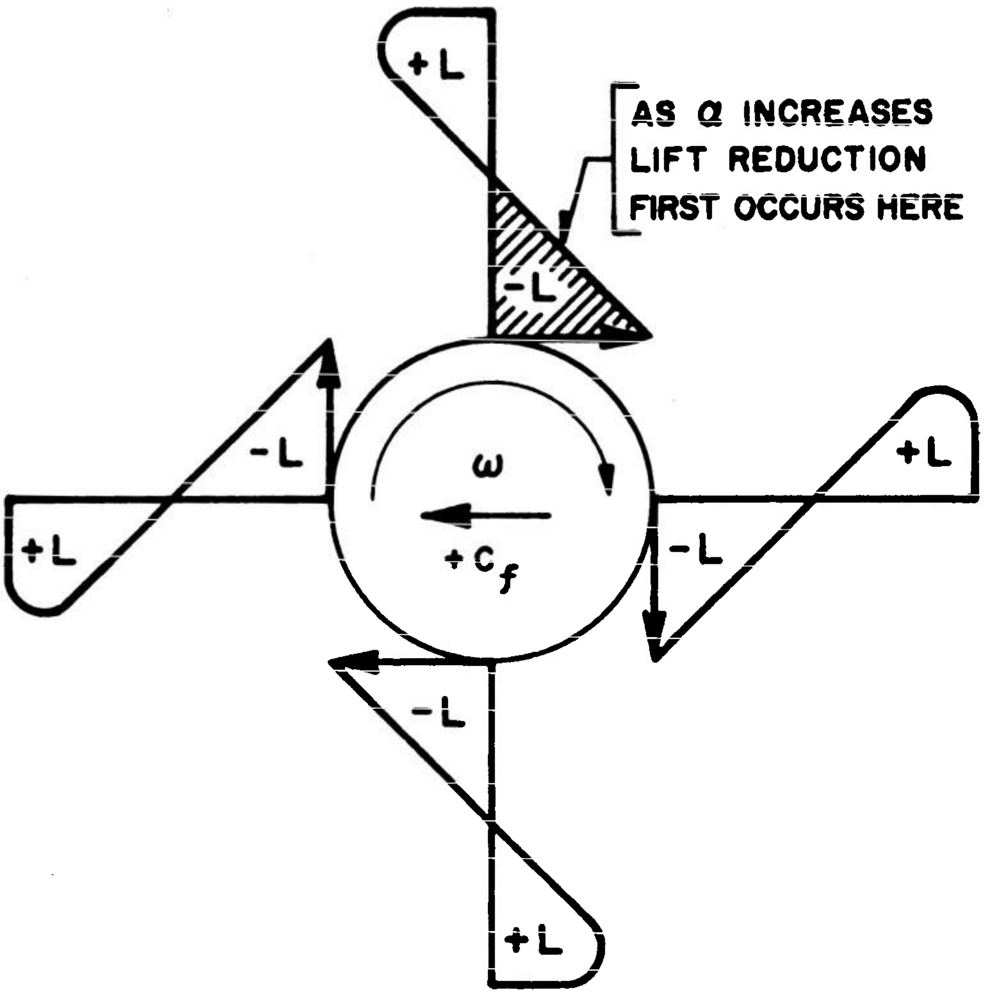


FINNED PROJECTILE CONFIGURATIONS

ALL DIMENSIONS IN CALIBERS
I CALIBER = 2.0 INCHES.

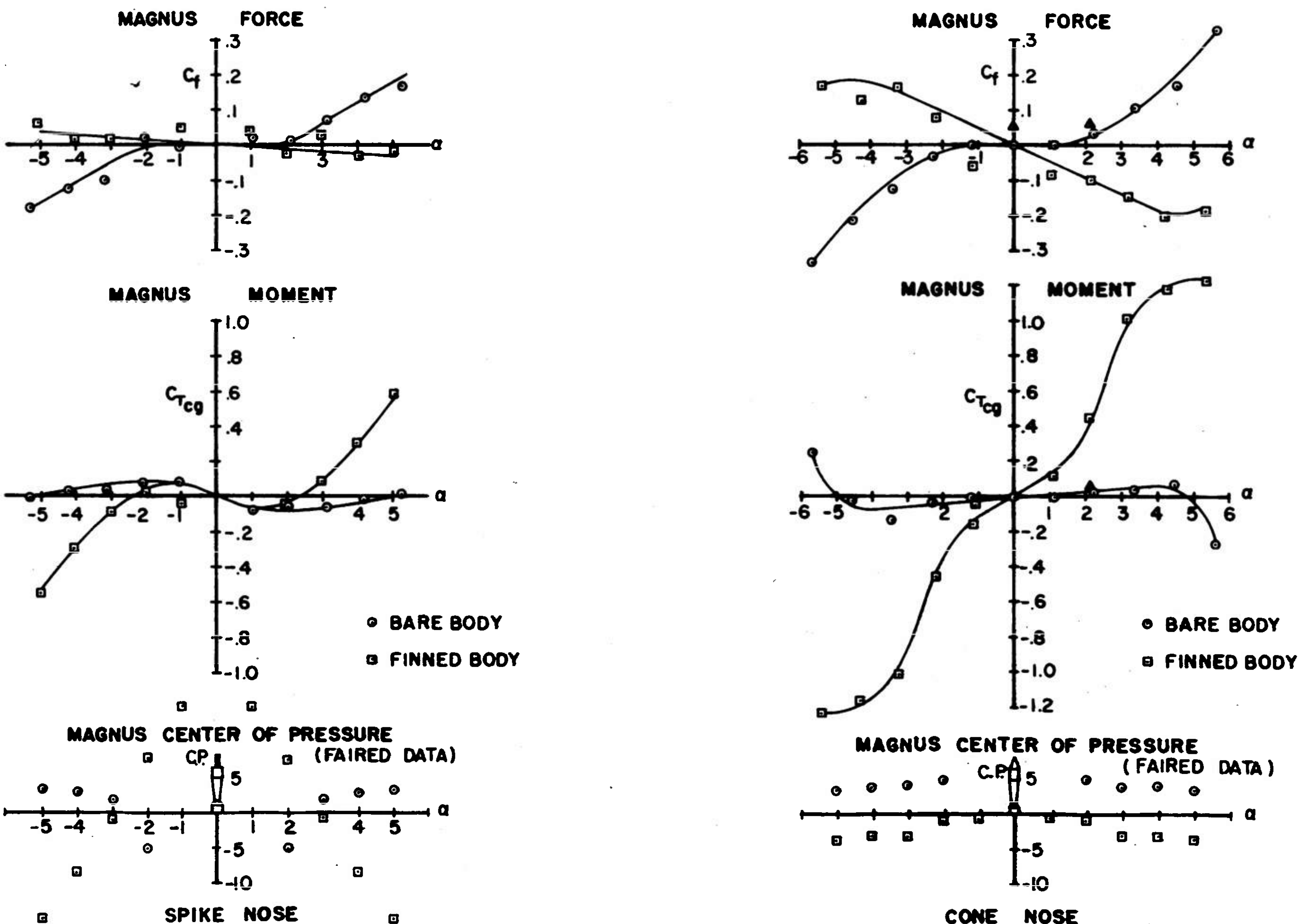
——— SPIKE NOSE
—-·-— CONE NOSE

FIG.3



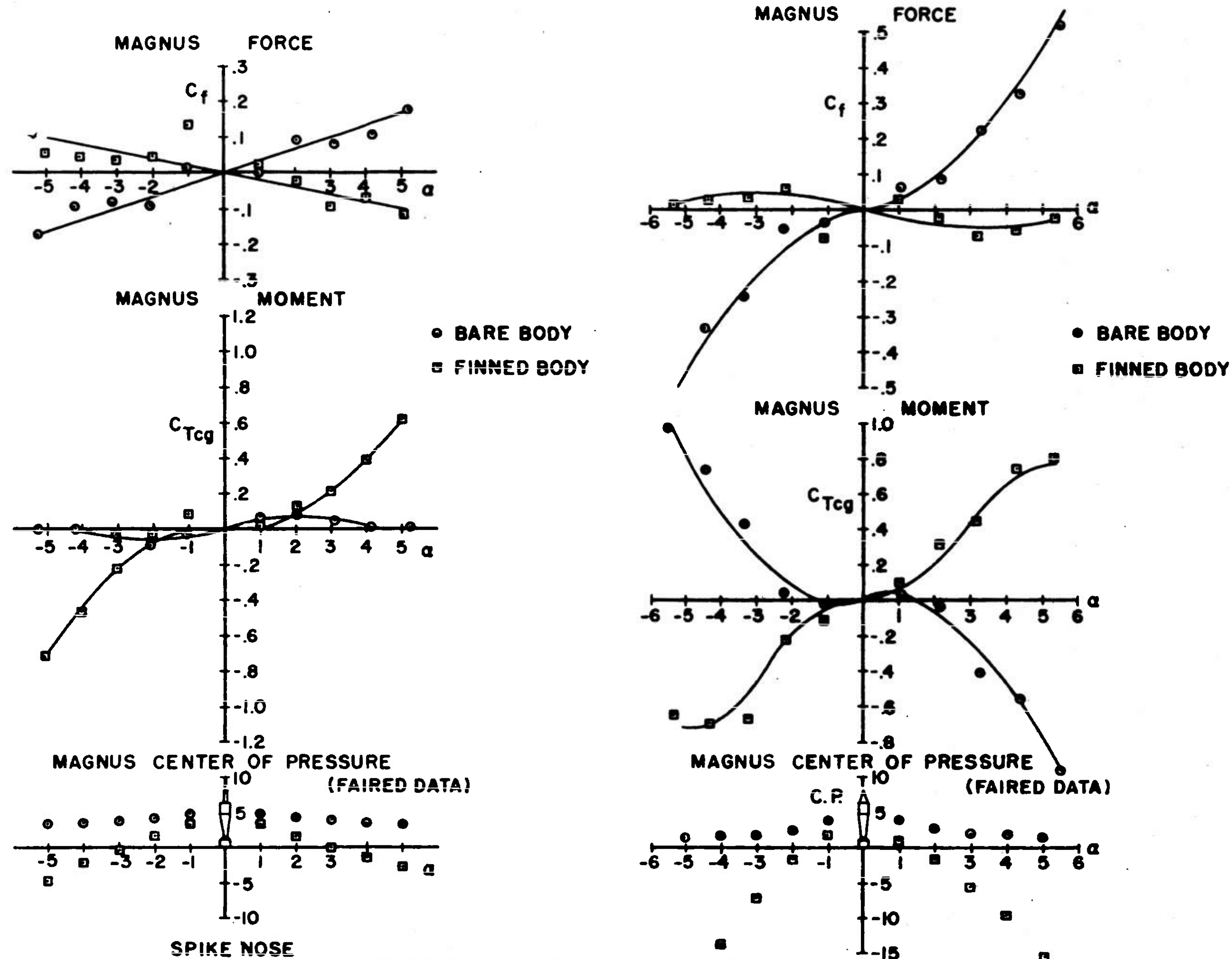
LIFT DISTRIBUTION ON SPINNING CANTED FINS

FIG. 4



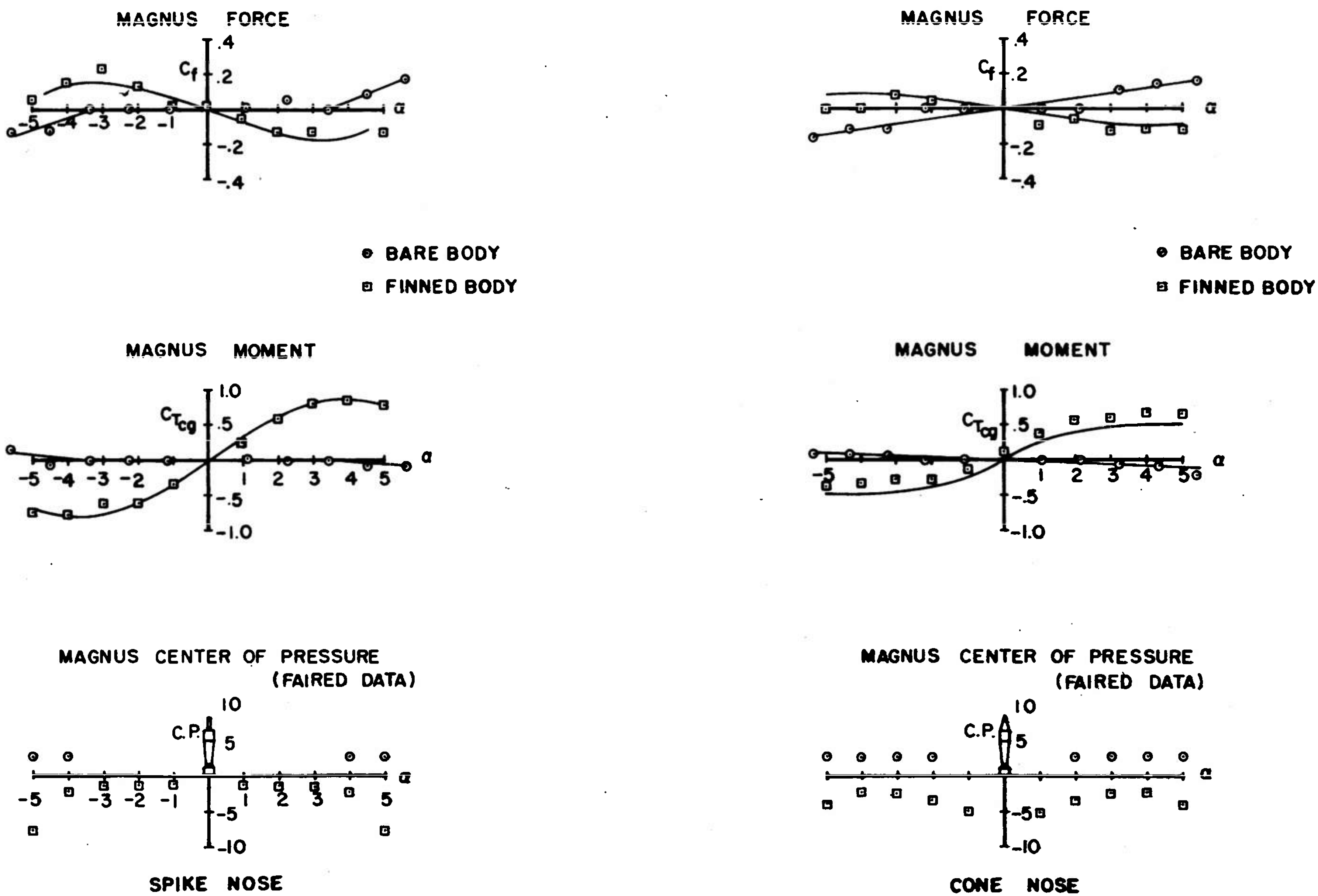
THE MAGNUS CHARACTERISTICS OF FINNED PROJECTILES AT M = 1.75 Re = .71 x 10^6

FIG. 5



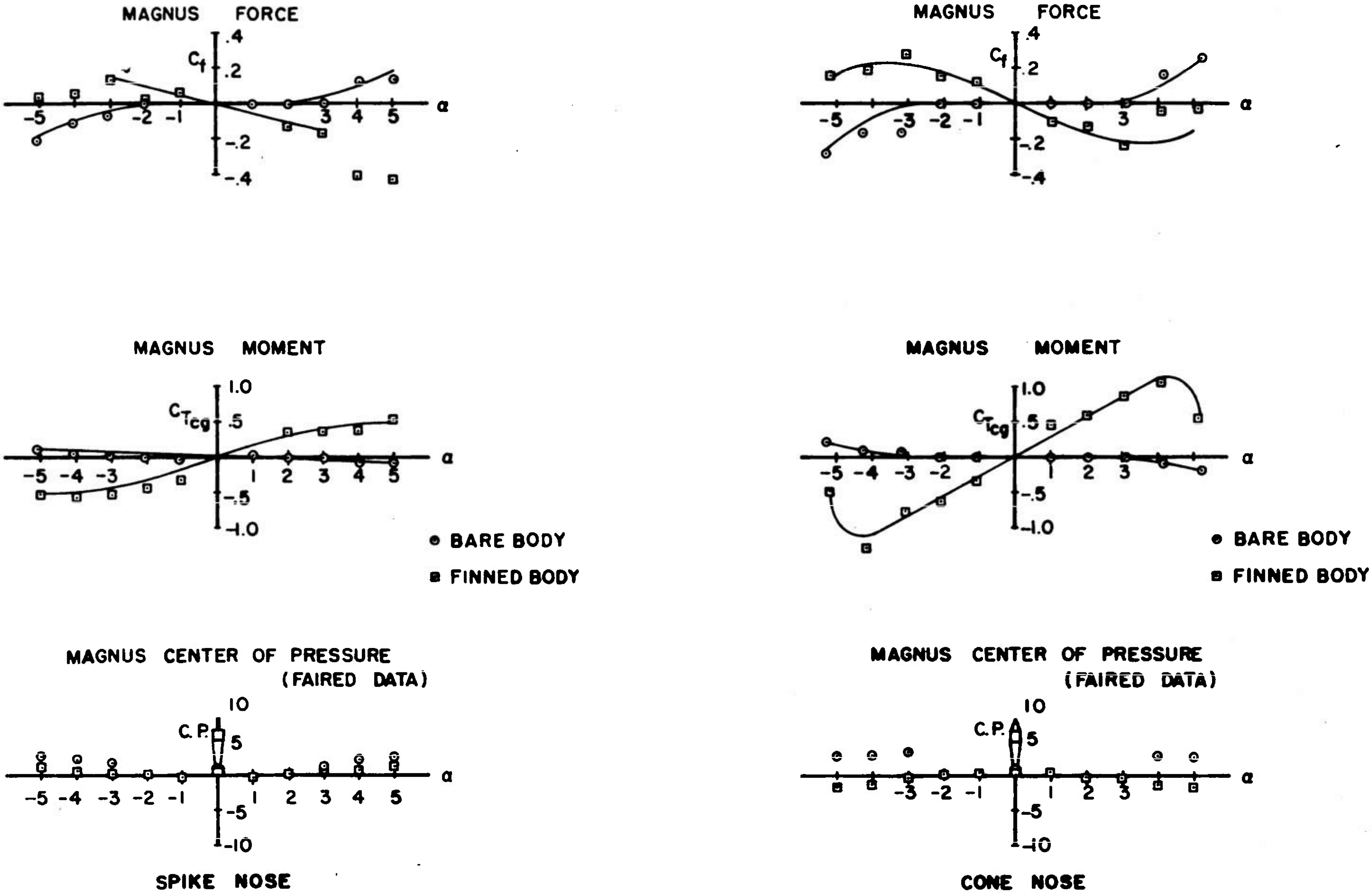
THE MAGNUS CHARACTERISTICS OF FINNED PROJECTILES AT M = 2.0 Re = .65 x 10^6

FIG. 6



THE MAGNUS CHARACTERISTICS
OF FINNED PROJECTILES
AT $M = 3.02$ $Re = .65 \times 10^6$

FIG. 7



THE MAGNUS CHARACTERISTICS
OF FINNED PROJECTILES
AT $M = 4.0$ $Re = .65 \times 10^6$

FIG. 8

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Ballistic Research Laboratories, APG
THE MAGNUS FORCE ON A FINNED BODY
Anders S. Platou

BRL Report No. 1193 March 1963

RDT & E Project No. 1A222901A201
UNCLASSIFIED Report

Finned stabilized projectiles - Magnus forces
Exterior ballistics - Theory
Wind tunnel tests - Finned projectiles

The effect of spin on the aerodynamic forces generated on a slowly spinning finned projectile is analyzed. Experiments in the BRL wind tunnels, which substantiate the analysis, are described and presented. It is seen that the Magnus forces and moments are as large as those existing on a rapidly spinning nonfinned projectile where these forces are known to have an influence on accuracy and stability.

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