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AERODYNAMIC CHARACTERISTICS OF A GENERAL TILT-WING/PROPELLER MODEL TESTED AT SLOW SPEEDS AND HIGH ANGLES OF ATTACK

By

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February 1968

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

CONTRACT DA 44-177-AMC-8(T)

PRINCETON UNIVERSITY
PRINCETON, NEW JERSEY

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This report has been reviewed by the U. S. Army Aviation Materiel Laboratories, the U. S. Naval Air Systems Command, and the U. S. Air Force Flight Dynamics Laboratory and is considered to be technically sound. The work was performed under Contract DA 44-177-AMC-8(T) to investigate the aerodynamic characteristics of a model wing/propeller tilt-wing aircraft in transition and hovering flight. Wing angles from 30 degrees (forward flight) to 90 degrees (hovering flight) in increments of about 5 degrees were investigated. The Princeton Dynamic Model Track was utilized to perform the investigation. This report is published for the exchange of information and stimulation of ideas.

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AERODYNAMIC CHARACTERISTICS OF A GENERAL TILT-WING/PROPELLER MODEL TESTED AT SLOW SPEEDS AND HIGH ANGLES OF ATTACK

Final Report

Aerospace Research Report 807

By

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Prepared by

Princeton University
Princeton, New Jersey

for

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FORT EUSTIS, VIRGINIA

SUMMARY

The aerodynamic characteristics of a general tilt-wing/propeller model were investigated at the Princeton Dynamic Model Track Facility. The experiments included test conditions corresponding to free-stream velocities from slow backward flight through hovering and transition. Wing incidence angles ranging from 30 degrees (forward flight) to 90 degrees (hovering flight) were investigated. The experimental data are presented in graphs of lift, horizontal force, and pitching moment versus thrust in coefficient form based on free-stream velocity.

FOREWORD

This research was performed by the Department of Aerospace and Mechanical Sciences, Princeton University, under the direction of Professor H. C. Curtiss, Jr., and the sponsorship of the United States Army Aviation Materiel Laboratories Contract DA 44-177-AMC-8(T), with guidance and financial support from the United States Navy, Naval Air Systems Command, and the United States Air Force Flight Dynamics Laboratory of the Research and Technology Division. The research was monitored by Mr. Robert P. Smith of the United States Army Aviation Materiel Laboratories.

The research was performed by Messrs. W. F. Putman, J. J. Traybar, and J. P. Kukon of the Flight Mechanics Laboratory, Princeton University.

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A propeller disc area, square feet

b propeller blade chord, feet

c chord length, wing, feet

c/4 quarter chord position, main wing

CL,FS,S lift coefficient based on free-stream q and wing area

$$\frac{L}{q_{fs} S}$$

CM,FS,S pitching moment coefficient based on free-stream q and wing area (about quarter chord)

$$\frac{M_y}{q_{fs} S c}$$

CT,FS,S free-stream thrust coefficient based on free-stream q and wing area

$$\frac{T}{q_{fs} S}$$

CT,SS,S slipstream thrust coefficient based on slipstream q and wing area

$$\frac{T}{q_{ss} S}$$

CX,FS,S horizontal force coefficient based on free-stream q and wing area

$$\frac{F_x}{q_{fs} S}$$

d propeller diameter, feet

F_x horizontal force, pounds

h′ propeller blade thickness, feet

L lift, pounds

M_y	pitching moment, about quarter chord point, foot-pounds
q_{fs}	free-stream dynamic pressure, $\frac{1}{2} \rho V^2$, pounds per square foot
q_{ss}	slipstream dynamic pressure, $q_{fs} + \frac{T}{2A}$, pounds per square foot
S	wing area, square feet
T	propeller total thrust, pcunds
V	free-stream velocity, feet per second
ρ	mass density of air, slugs per cubic foot

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INTRODUCTION

A series of tests was conducted to investigate the aerodynamic characteristics of a model wing/propeller combination in the flight envelope normally encountered by a tilt-wing aircraft in transition and hovering flight. The forces and moments measured are presented in coefficient form for wing angles from 30 to 90 degrees and free-stream velocities representing backward, hovering, and forward flight. The nondimensionalization of the coefficients is based on free-stream velocity. Test points about trim (horizontal force equal to zero) were obtained. Commensurate with the capabilities of this test facility, propeller thrust and free-stream velocity were selected to correspond dimensionally to those of Reference 2.

MODEL AND APPARATUS

The generalized tilt-wing model used for the investigation is shown mounted on a sting type balance system in the 30-by-30-foot test section of the Princeton Dynamic Model Track Facility (Figure 1). The wing is identical to the one tested by the NASA (Reference 2) except that its weight has been greatly reduced. The propellers, motors, and strain gauge were borrowed from the NASA and installed on the Princeton model. A scale drawing is shown in Figure 2 to display the relative size of the model and facility test section with regard to blockage and wall effects. The model is shown at a wing angle of about 90 degrees in Figure 2 and about 50 degrees in the photograph, Figure 1. The configuration, pertinent dimensions, and characteristics of the wing and propellers are presented in Figures 3 and 4. The systems of axes and notation used in this report are shown in Figure 5.

A 1/8-inch transition strip of number 60 Carborundum (0.012 mean grain diameter) was installed on the wing leading edge of the model at 8 percent chord. The model had two propellers and nacelles but no fuselage. A sting balance mount entry was provided by a 5-by-2.7-inch tunnel located at mid-span of the wing from maximum thickness aft to the trailing edge (Figure 3). The wing angle was varied about a pitch center attachment (referenced to the quarter chord) on the moving carriage so that no variations of the model pitch center with respect to wall clearance occurred. The model was positioned in the center of the 30-by-30-foot test section.

The total forces and moments were measured on a six-component internal strain gauge balance (NASA-711 strain gauge). The measured total forces and moments were transferred from the balance pitch center to the quarter chord point of the wing. The model motors were also mounted on strain gauge beams to measure propeller thrust independent of the main balance.

All tests were conducted at the Princeton Dynamic Model Track Facility (Reference 1). This is a unique facility designed for the study of the dynamic and static stability and control of helicopters and V/STOL-type configurations for the speed regime ranging from hover through transition. Basic components of the facility include a test section building with a cross section of 30 by 30 feet, an automated servo-controlled powered carriage that rides on a 760-foot-long track, a carriage-model computer, various model mounts, measuring transducers, and data conditioning and recording equipment. The various mounts permit unique methods of attaching the models to the carriage so that the classical longitudinal and lateral/directional degrees of dynamic motion may be studied. Also, special mounts may be used for transition experiments, static tests, and "ground effect" research.

Although the facility was designed primarily to conduct dynamic testing, certain features make it especially well suited for the type of static testing desired in this research program. Numerous static stability research programs on V/STOL-type configurations for the hover and transition speed range have been conducted on this apparatus. This form of testing is similar to conventional wind tunnel testing (though perhaps not as efficient) but with the added advantages of the large 30-by-30-foot test section, precise airspeed measurement under all flight conditions, and a uniform velocity profile, air flow condition free from turbulence (still air). The benefits obtained from these controlled test conditions are important since they frequently make the difference between useful and questionable data for this difficult flight regime.

When this apparatus is used for static testing, a variety of different programs may be used to vary or control test quantities. Velocity may be pre-programmed to selected constant velocities or may vary very slowly about a trim condition for "quasi-steady" type data. Also, thrust (in this case) may be held constant, or it may vary during a run. All tests were conducted with wing angle fixed (approximately 5-degree increments between 30 degrees and 90 degrees).

EXPERIMENTAL DATA

All data are presented in plots in coefficient form of lift, horizontal force, and pitching moment versus thrust for the various wing angles. Much of the range of coefficients covered was governed by Reference 2. Within the capabilities of the Princeton Dynamic Model Track, efforts were made to duplicate, dimensionally, the test points obtained in Reference 2.

When a wing is operating entirely within the slipstream of the propellers, large moments and forces may be produced even at the lower free-stream velocities. The facility can easily cover the slow-speed end of the tests, but the high speeds were limited to a maximum speed of about 45 feet per second. Since the method of nondimensionalization used for this report was selected to be similar to Reference 2 (so that results of these data may be compared to that work), certain well-known difficulties are encountered. Coefficients based on free-stream dynamic pressure approach infinity as the free-stream velocity tends toward zero and approach zero as the free-stream velocity increases (Figure 6).

It is important to note that for these types of tests, another form of coefficient is generally calculated based on slipstream dynamic pressure and uses a variety of symbols such as ($C_{T,s}$), (T_c''), (C_L'') (References 2 and 3). In this report, the use of automated printing equipment necessitated still another type of symbol (CT,SS,S), denoting that the thrust coefficient (CT) is based on slipstream dynamic pressure (SS) and total wing area (S). The different symbols all denote the same quantity, and a simple expression relates the free-stream thrust coefficient and the slipstream thrust coefficient (Figure 7).

$$\mathrm{CT,SS,S} = \frac{\mathrm{CT,FS,S}}{1 + \mathrm{CT,FS,S}} \qquad (1)$$

Some attention must be paid to the characteristic area (wing area or propeller disc area) used in nondimensionalization. In this report (as in Reference 2), wing area (S) was used for the thrust coefficients (instead of propeller disc area, A) as well as for the coefficients of lift, horizontal force, and moment, so that they would have a common relationship. As it happens, the total propeller disc area (6.28 square feet) and the total wing area (6.34 square feet) are approximately equal ($S/2A \approx 1$), so that equation (1) is reasonably accurate. If the areas are much different, equation (1) would include an area ratio in the denominator.

Thrust and free-stream velocity were varied over the widest ranges permissible in this facility so that the greatest coverage of coefficients would be obtained to match the ranges covered in Reference 2. Additional points not covered in the aforementioned reference were also tested. Thrust coefficients based on slipstream dynamic pressure varied from approximately 0.5 (thrust equal to 7 to 8 pounds at forward speeds of 40 to 45 feet per second, wing angle equal to 30 degrees) to 1.0 (thrust equal to 40 to 50 pounds at hovering, wing angle equal to 90 degrees). Attempts were made to obtain the data about trim (horizontal force equal to zero) for all wing angles tested.

All experimental data shown in this report were taped in analog as well as digital form. Use was made of an analog-to-digital converter to record the data in standard IBM compatible binary coded decimal form, and the data were reduced on IBM 7094 equipment. Also, digital plotting routines and programs utilizing the IBM 1620 were used to plot all data graphs.

RECOMMENDATIONS

The nondimensionalization used in this report and others is inconvenient for analysis of the aerodynamic characteristics of these configurations at slow speeds and high wing angles. Further considerations should be given to other methods of presenting these data for transition and near hovering flight cases. Additional analyses of the data should be made to separate the propeller and wing forces and moments to gain further insight into the aerodynamic characteristics of a wing/propeller combination at slow speeds and high angles of attack.

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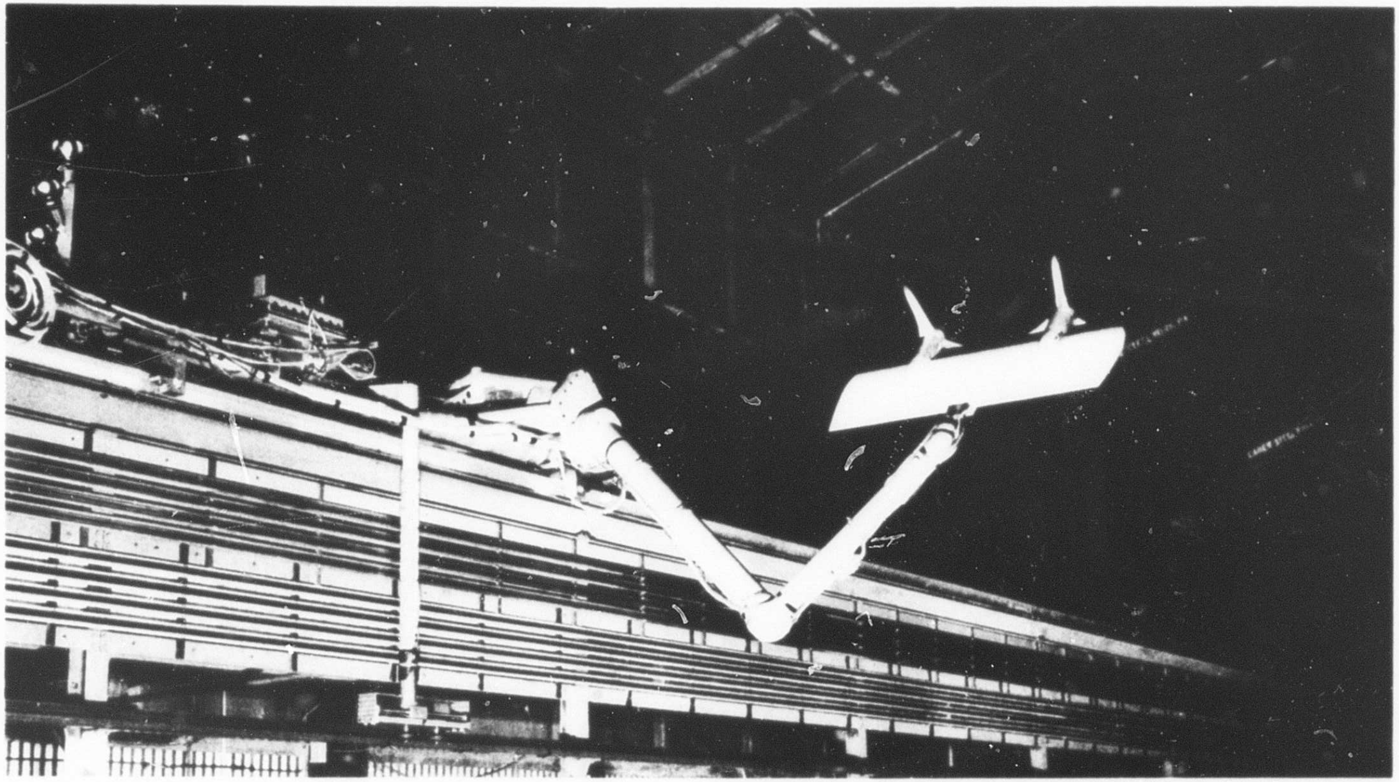
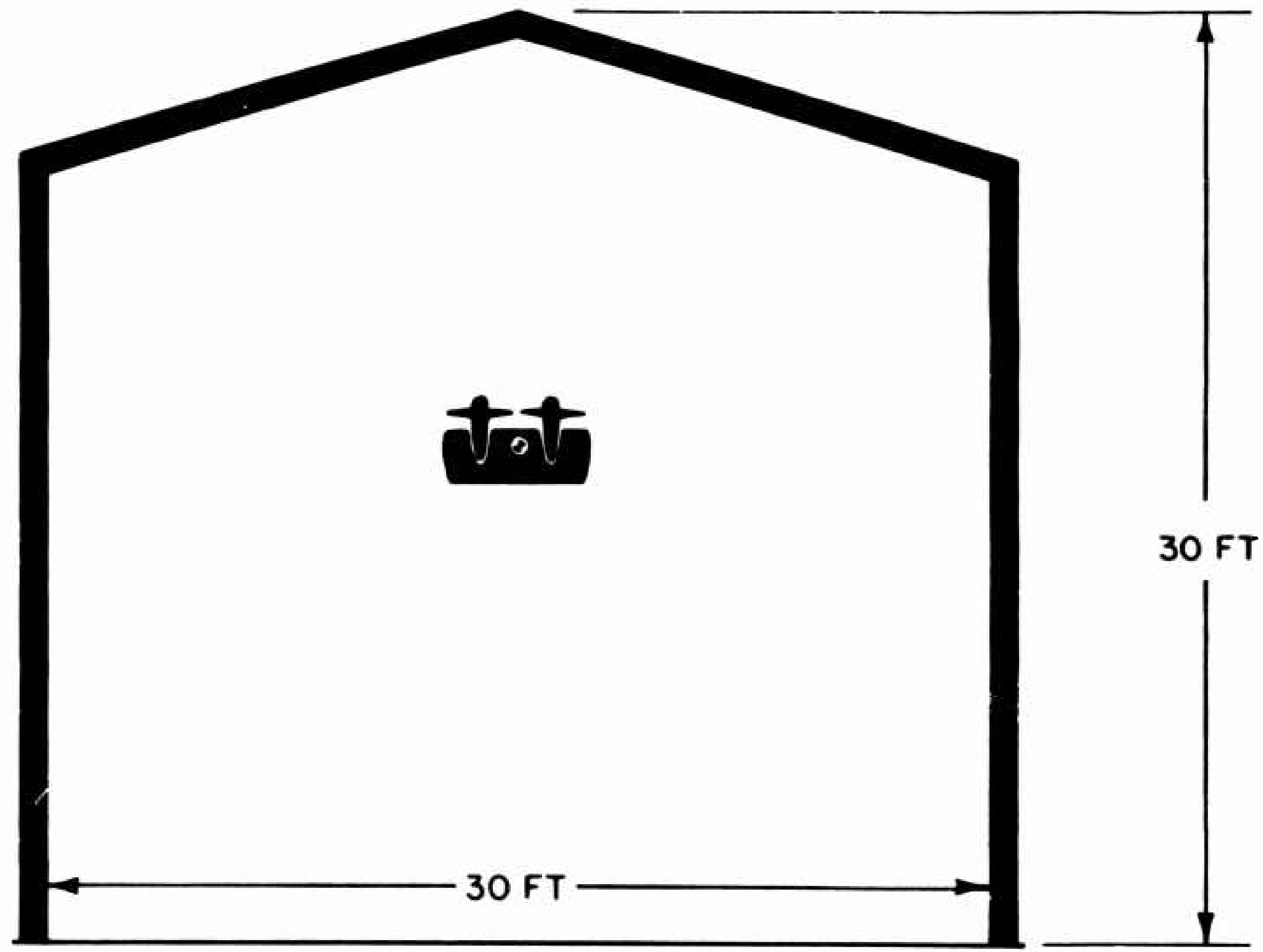


Figure 1. Model Installation in 30-by-30-Foot Test Section of the Princeton Dynamic Model Track Facility



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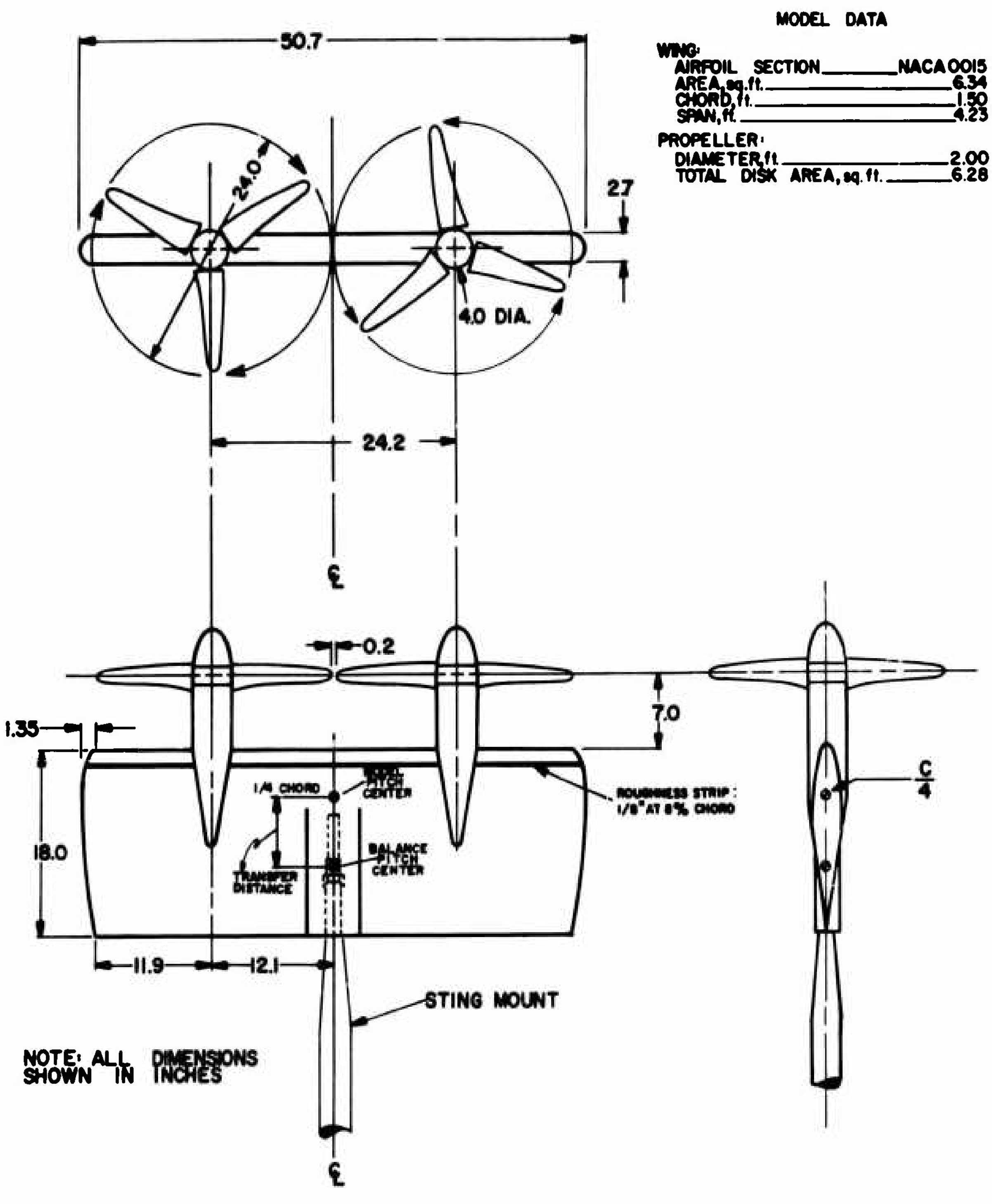


Figure 3. Tilt-Wing/Twin Propeller Mode_ Configuration

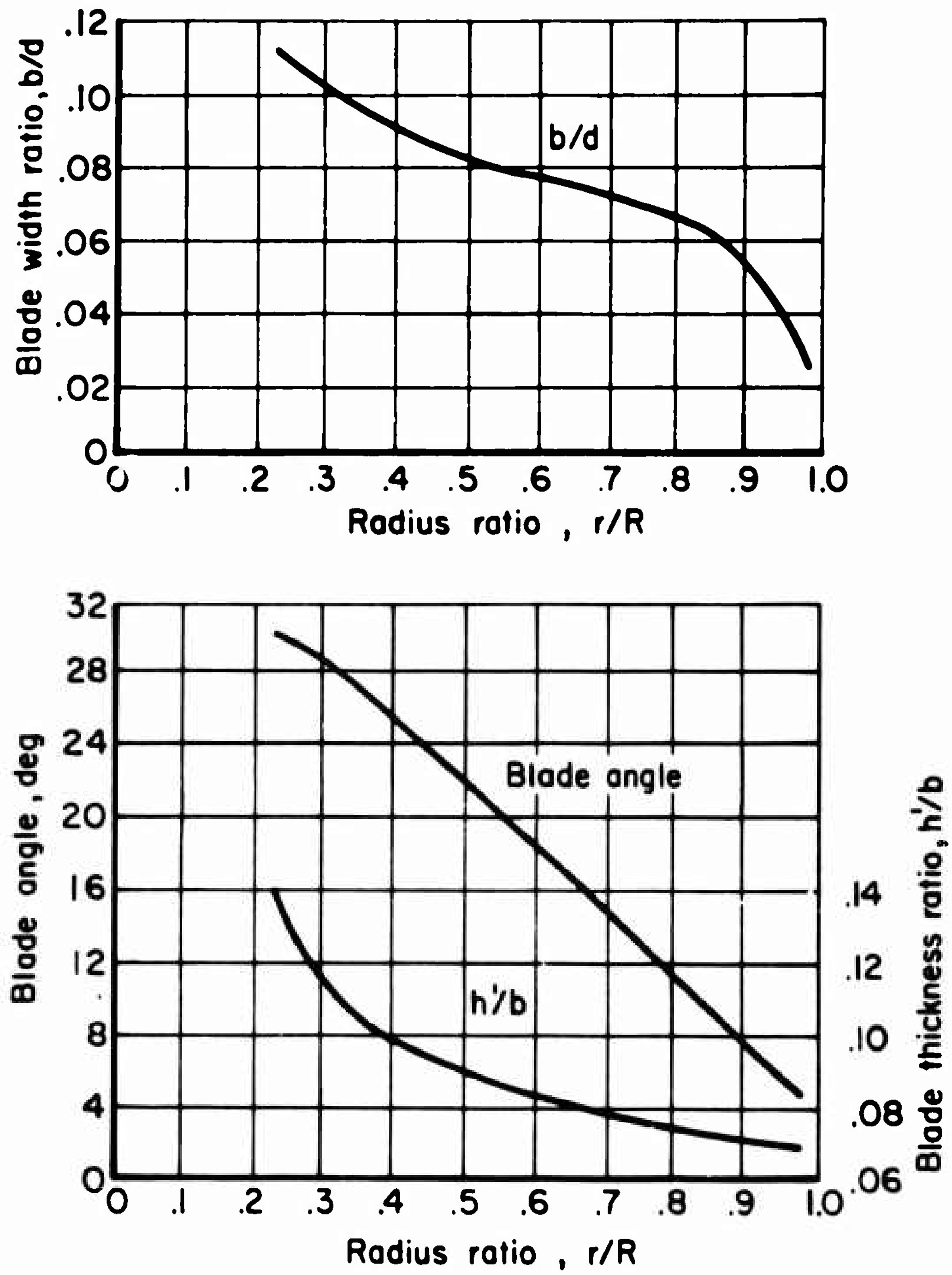
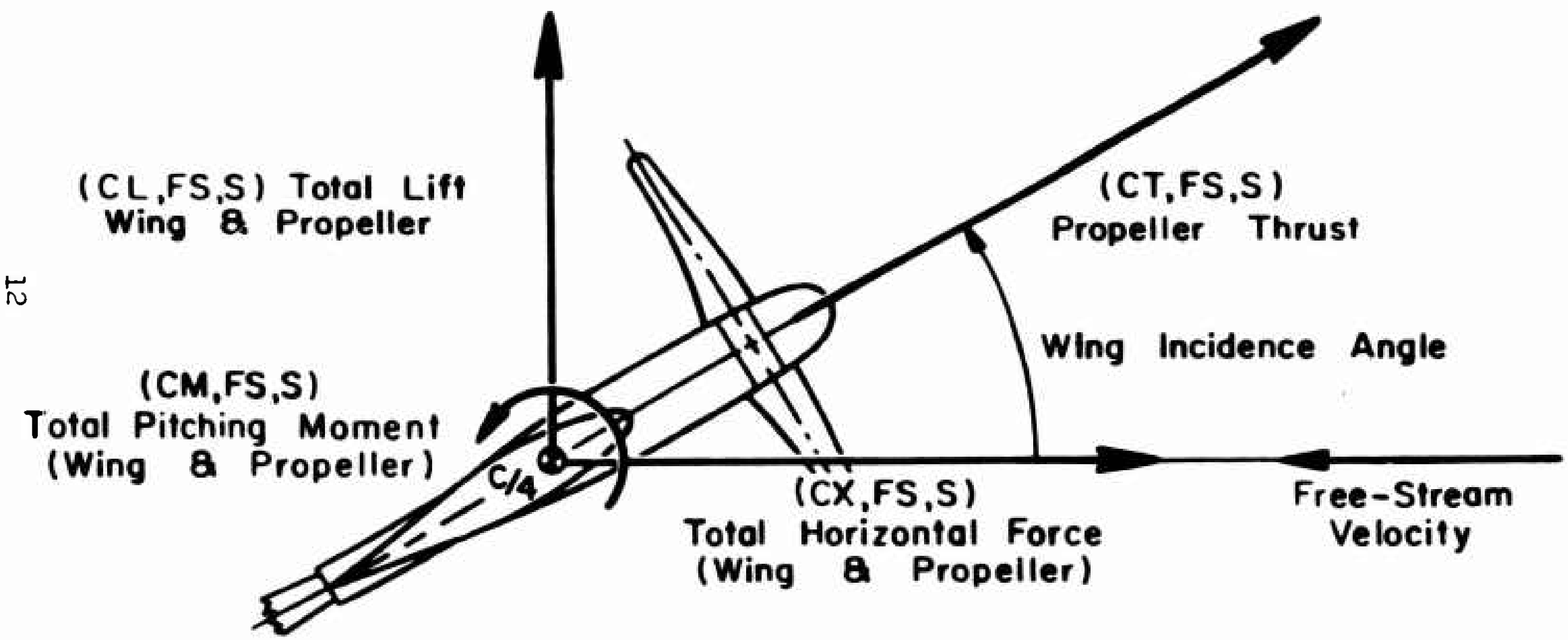


Figure 4. Propeller Blade Form Curves



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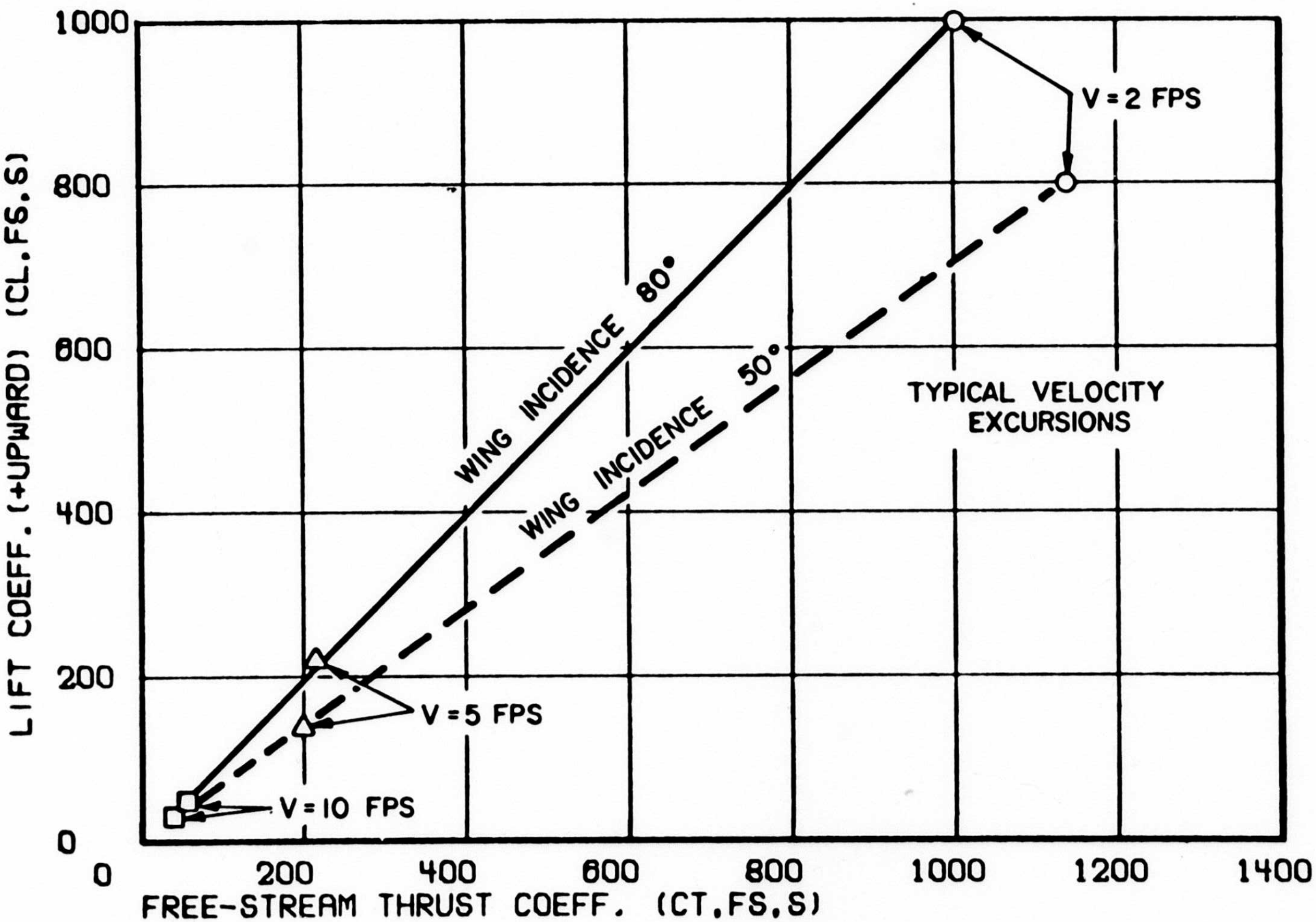

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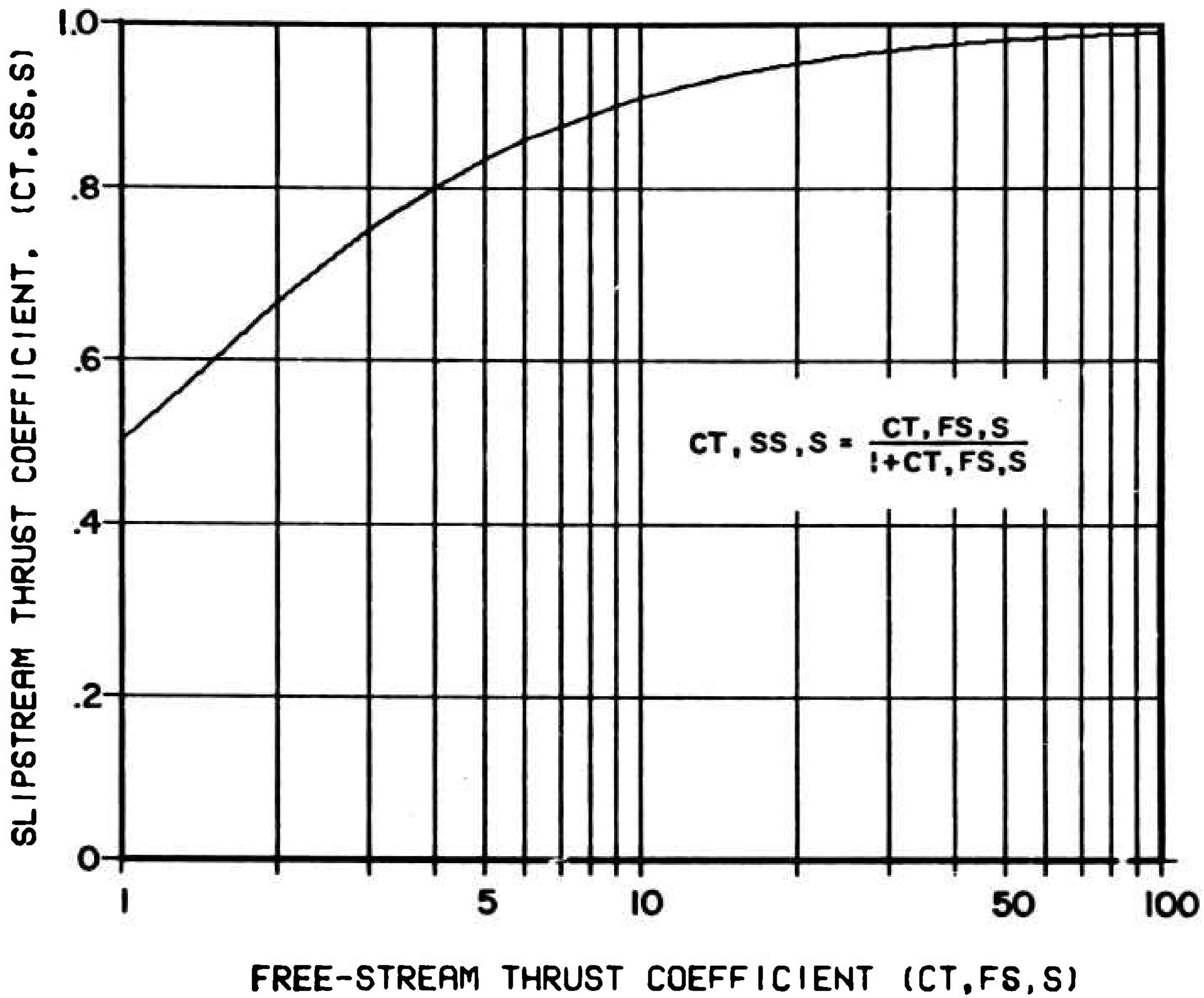


Figure 7. Plot Showing Relationships of Thrust Coefficient Based on Free-Stream Dynamic Pressure and Slipstream Dynamic Pressure

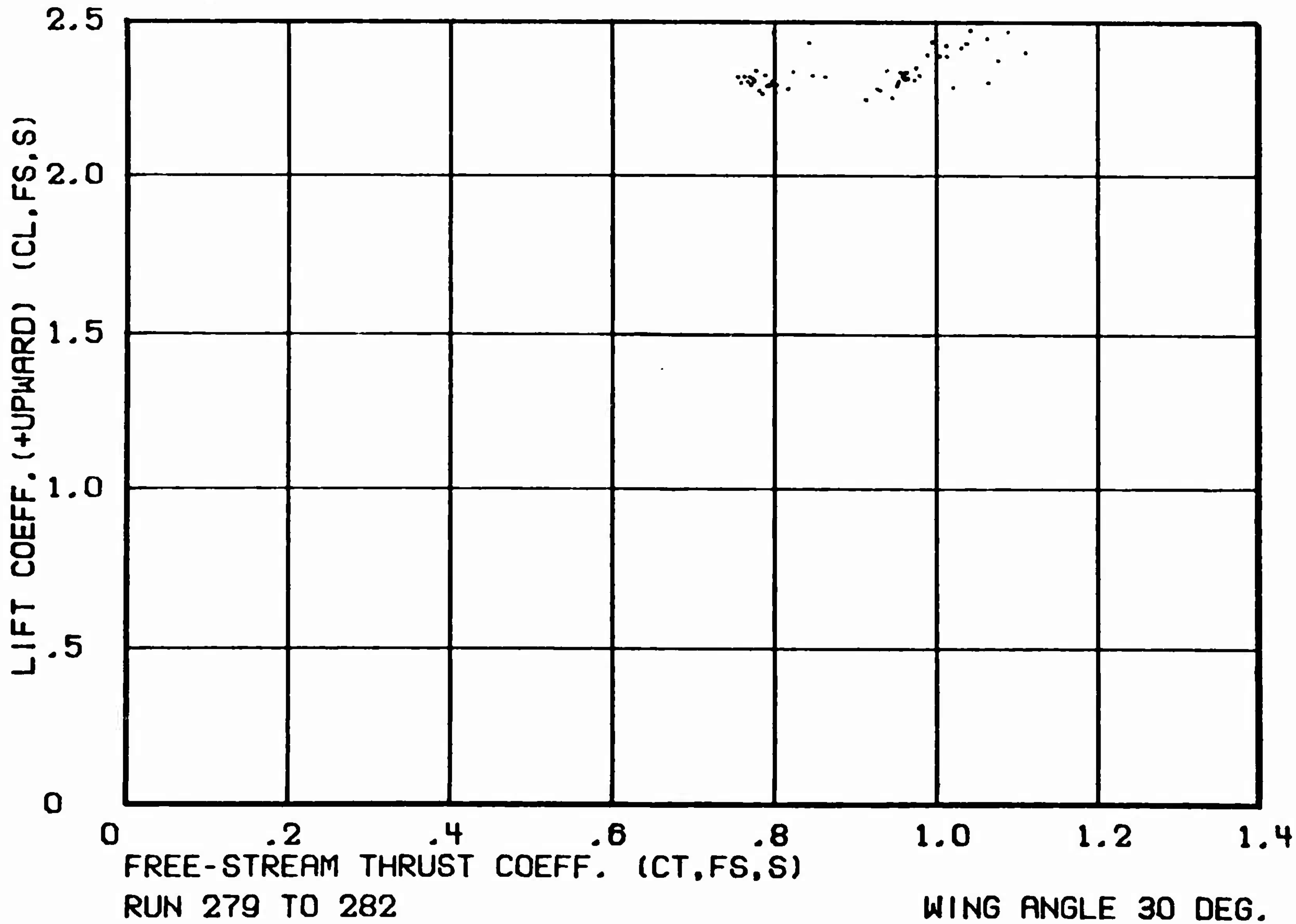


Figure 8a. Propeller-Wing Data

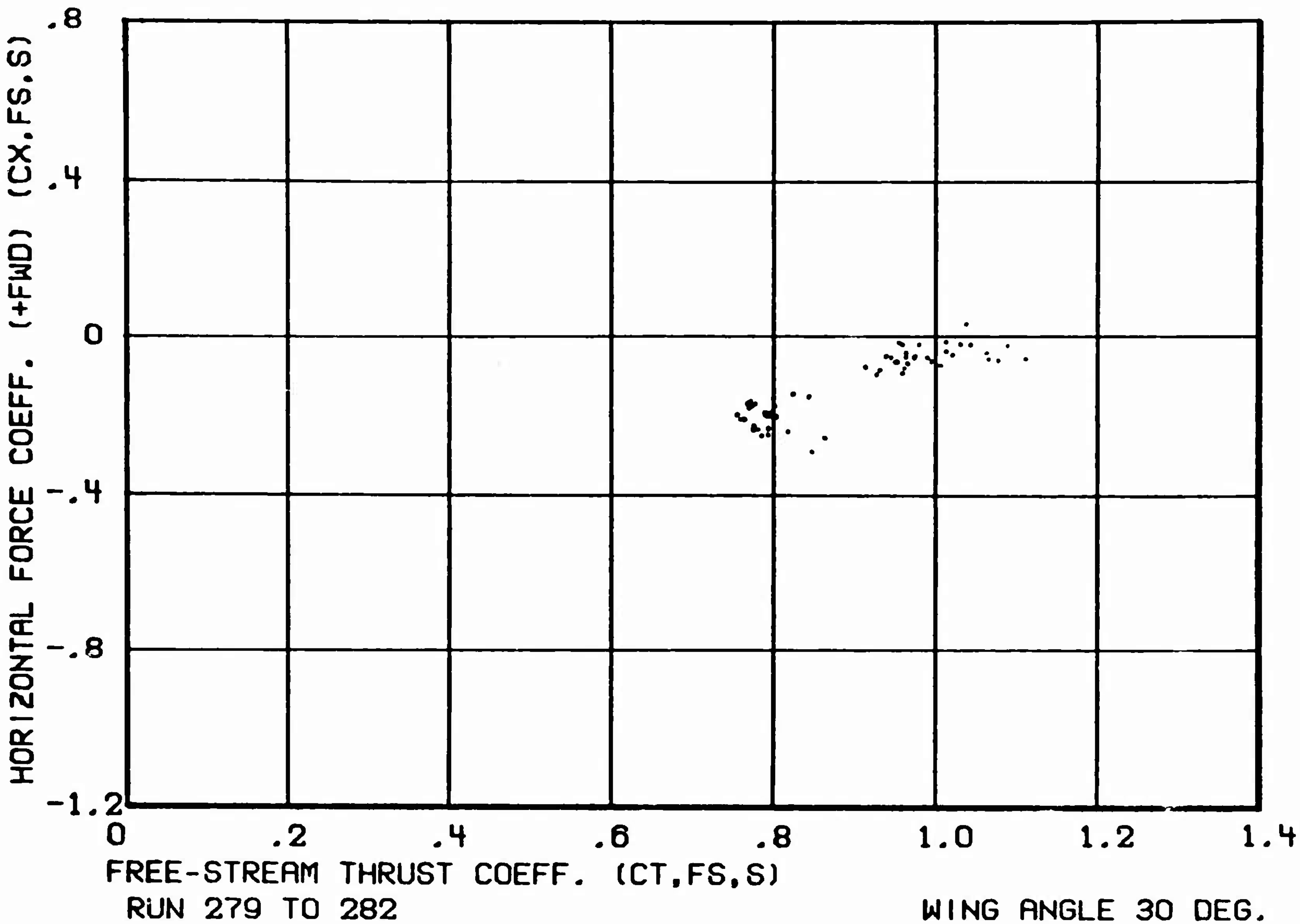
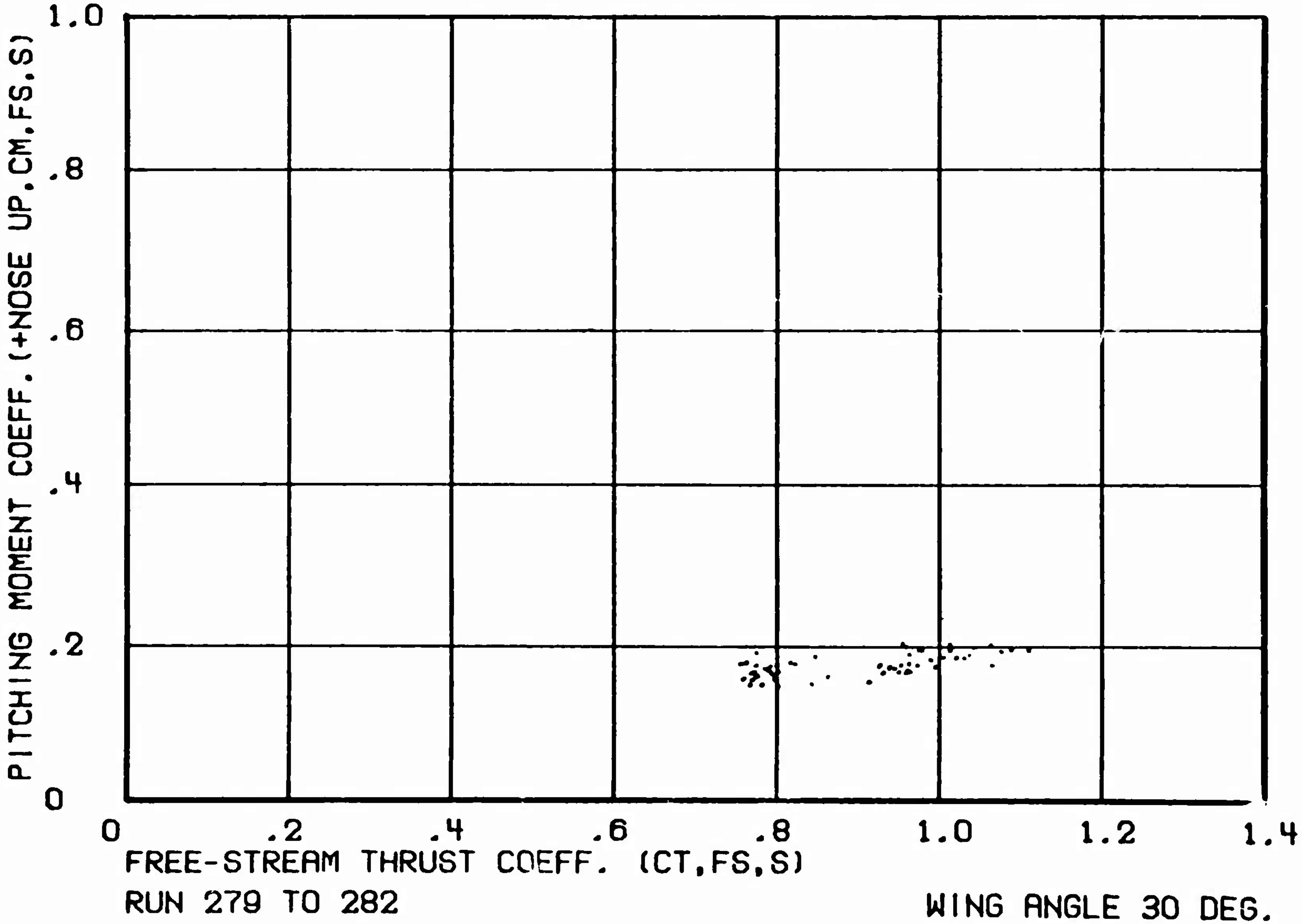


Figure 8b. Propeller-Wing Data



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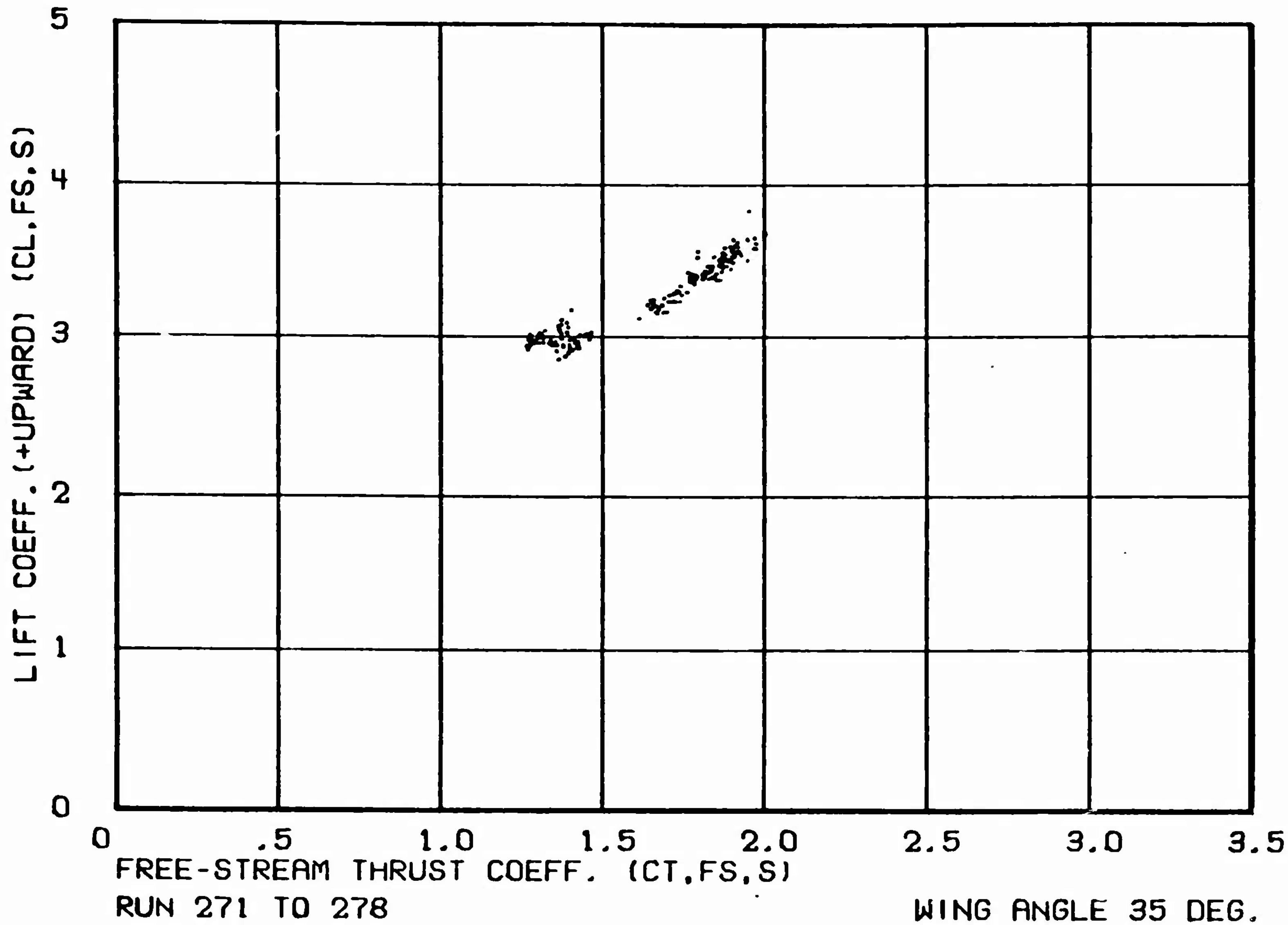

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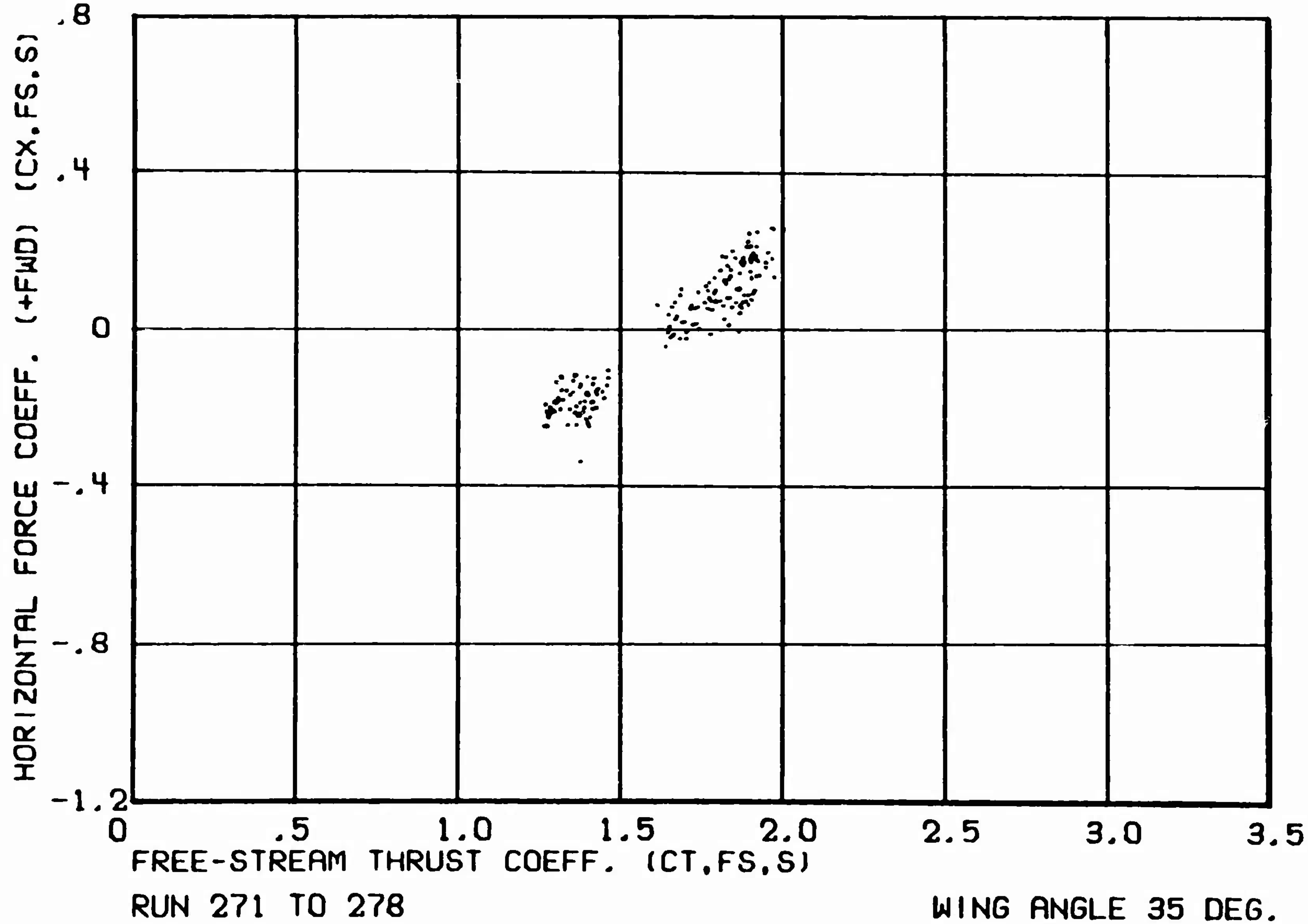

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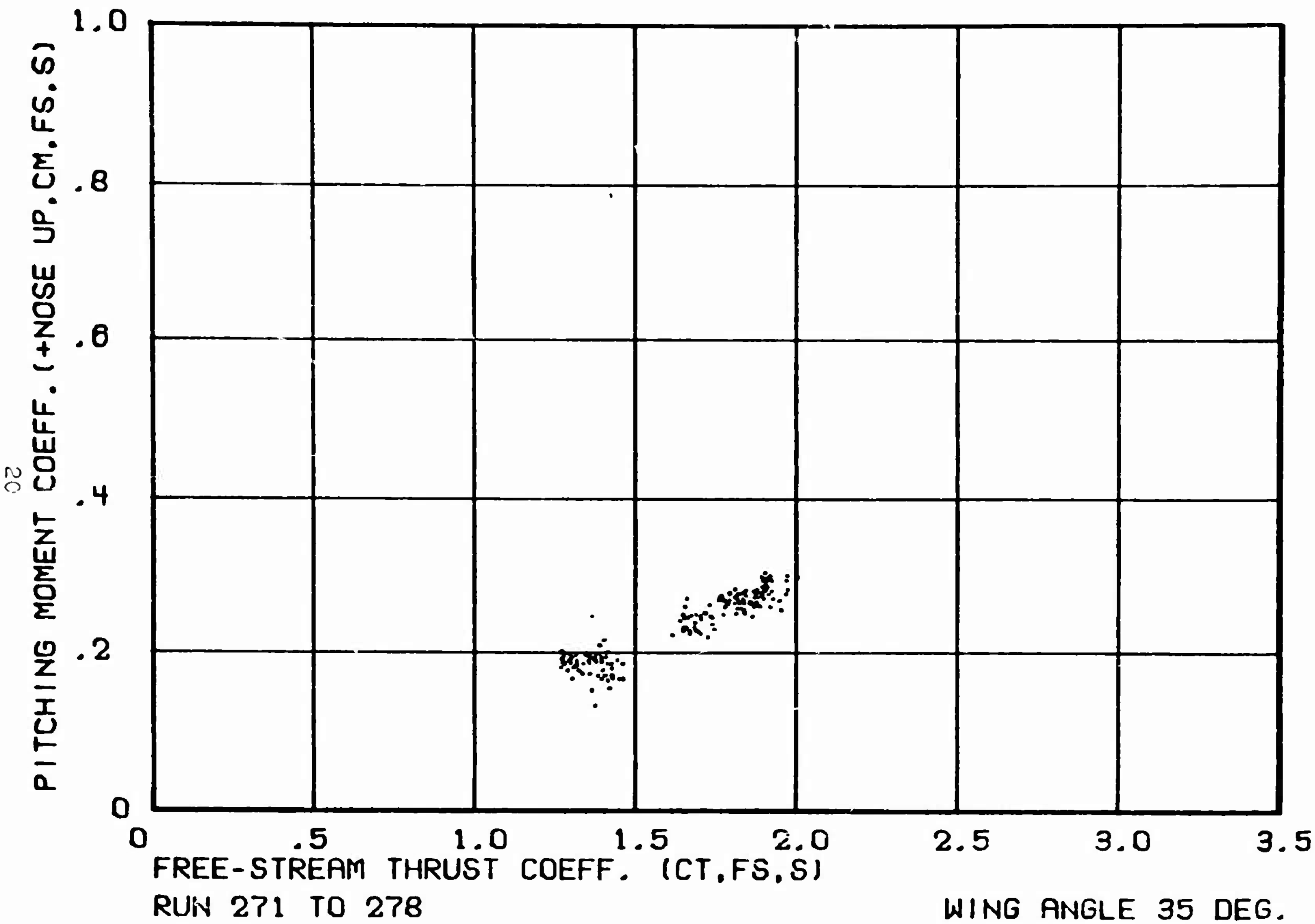

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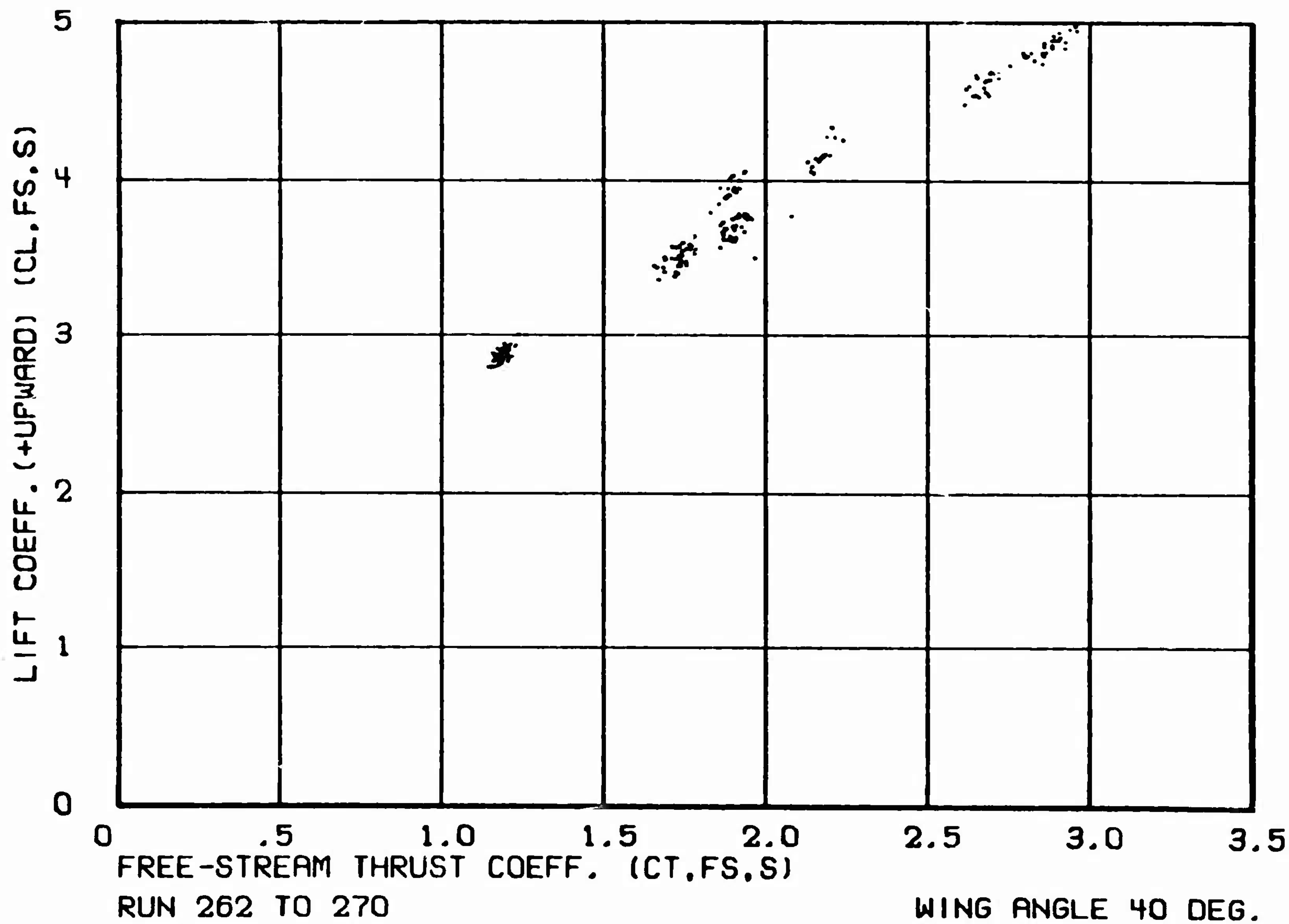

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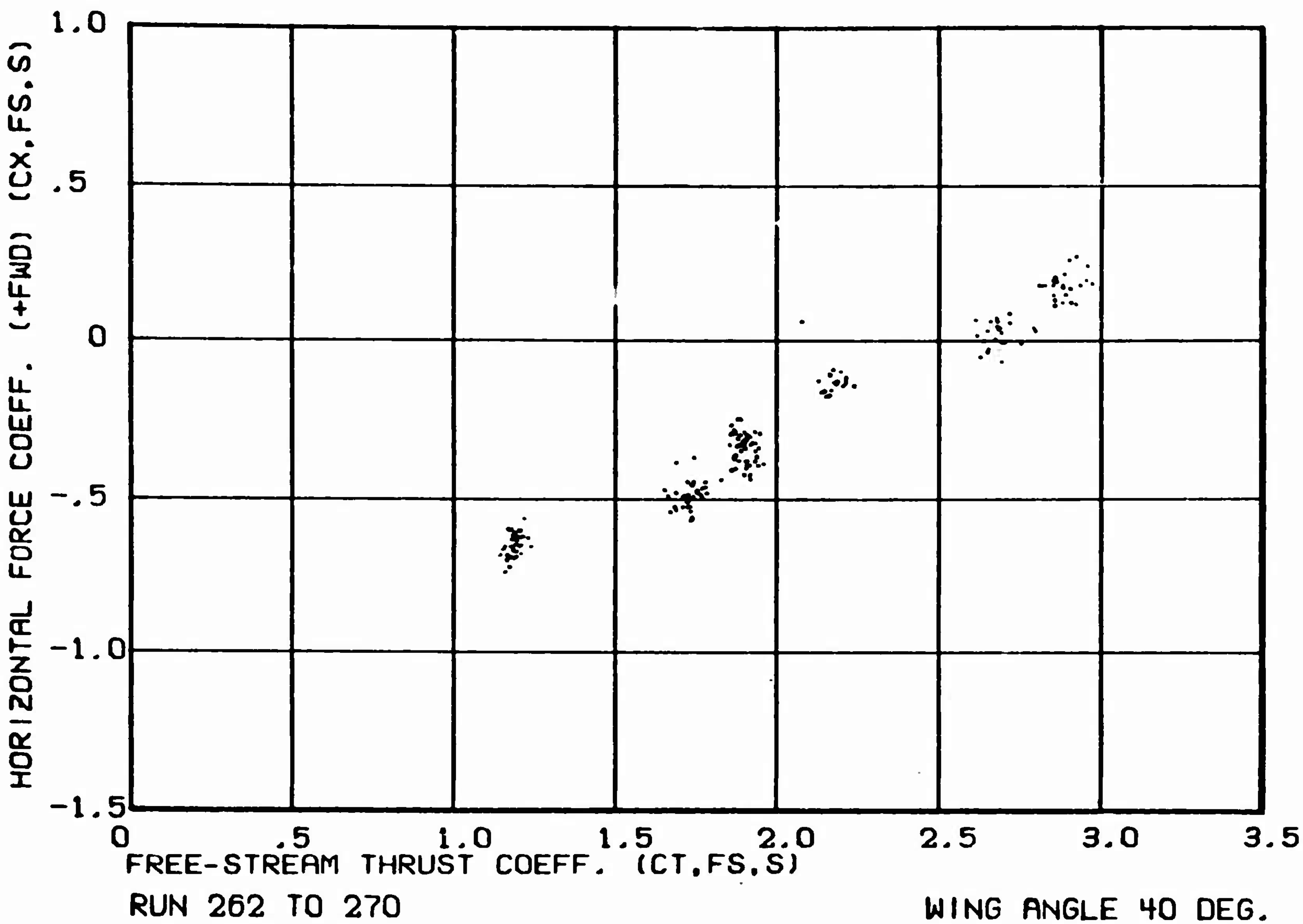

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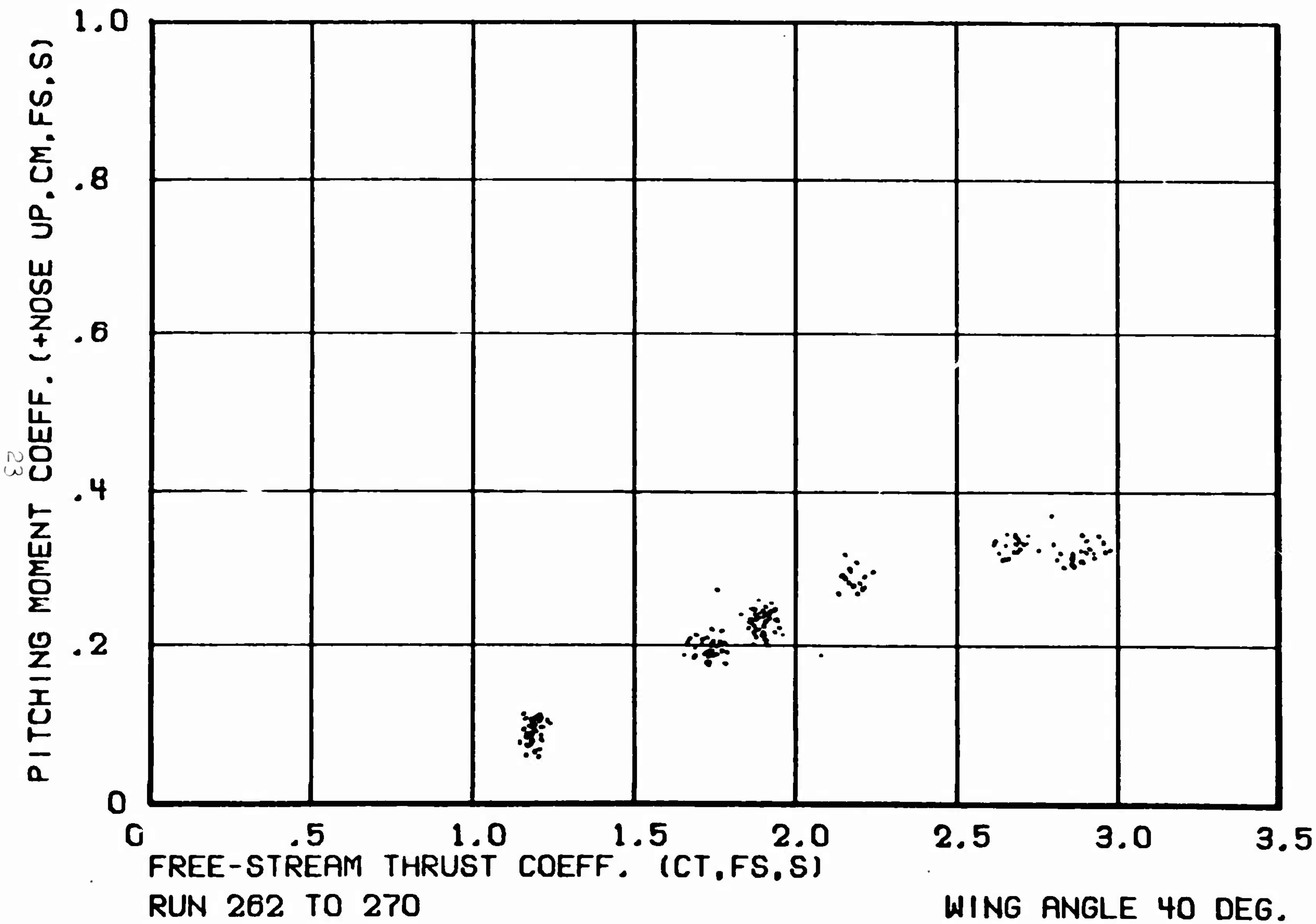

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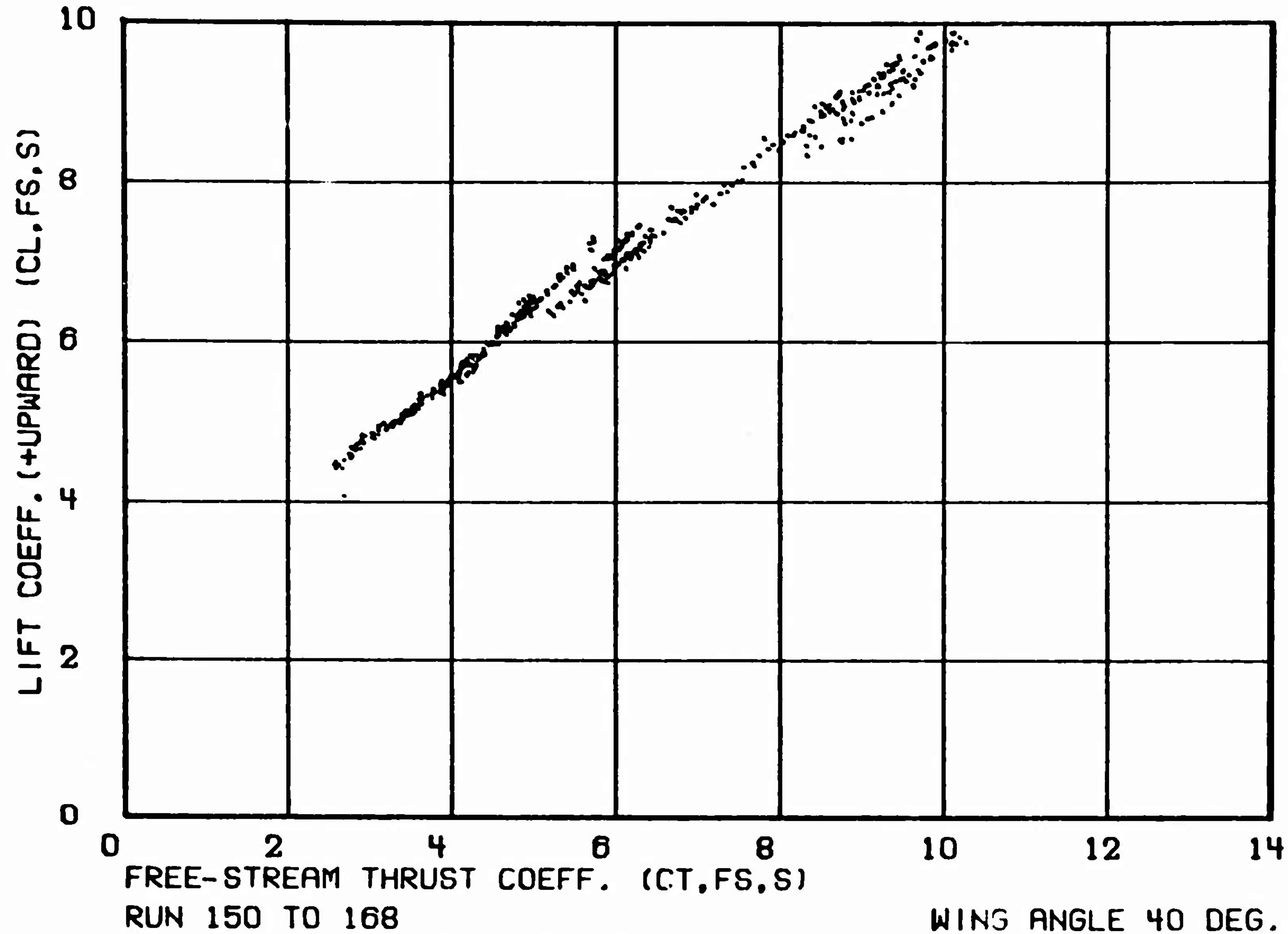

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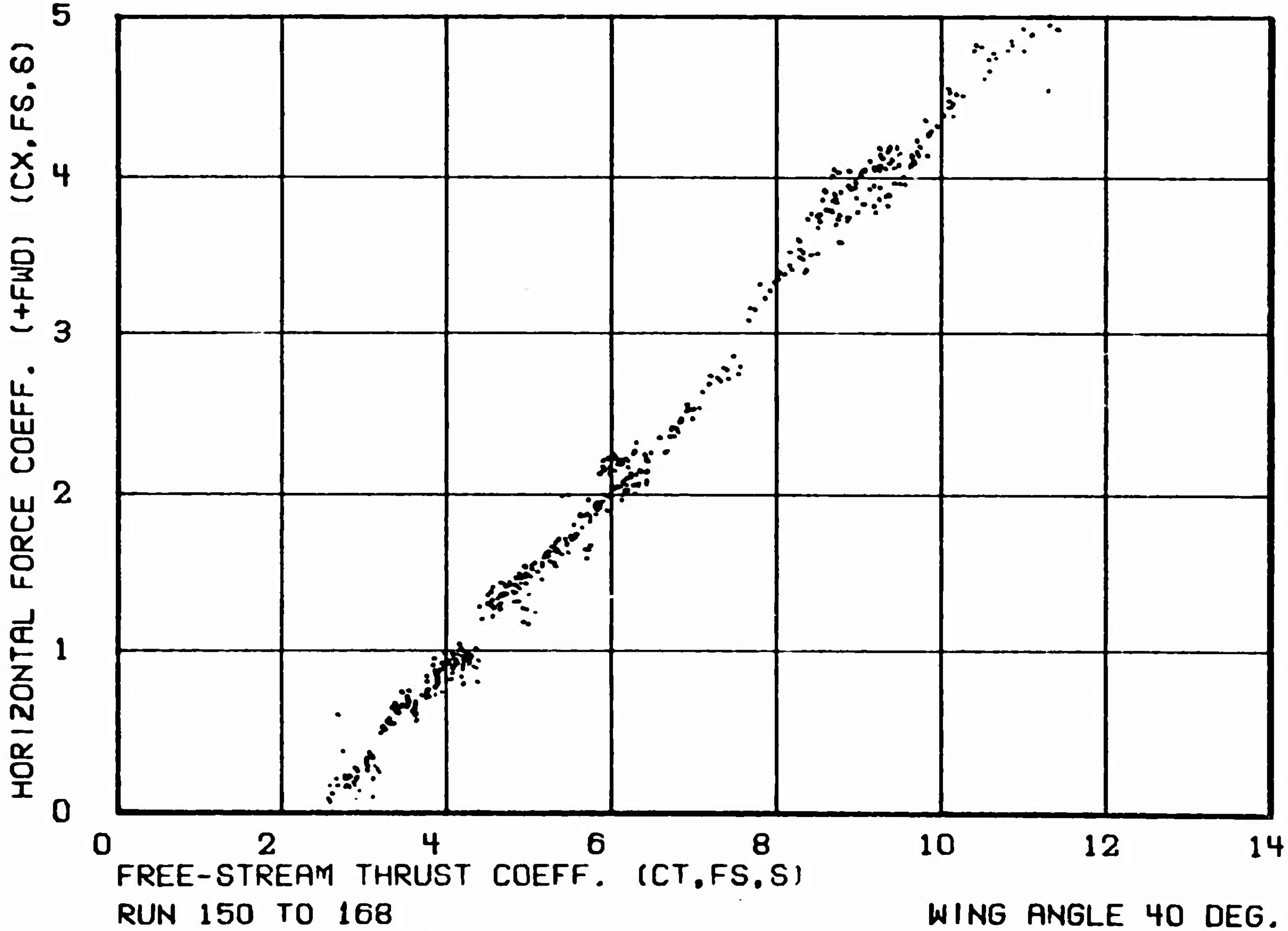

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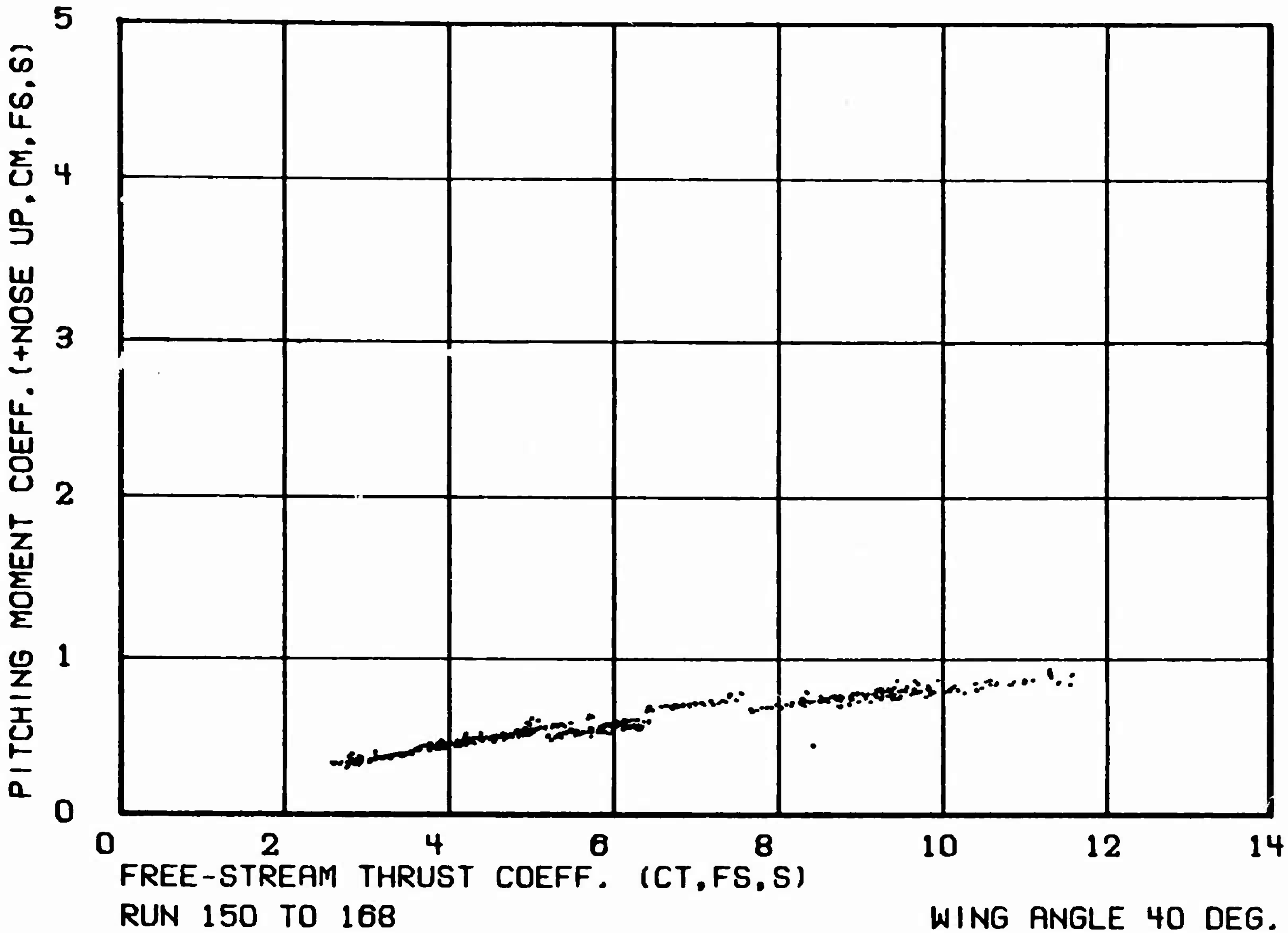

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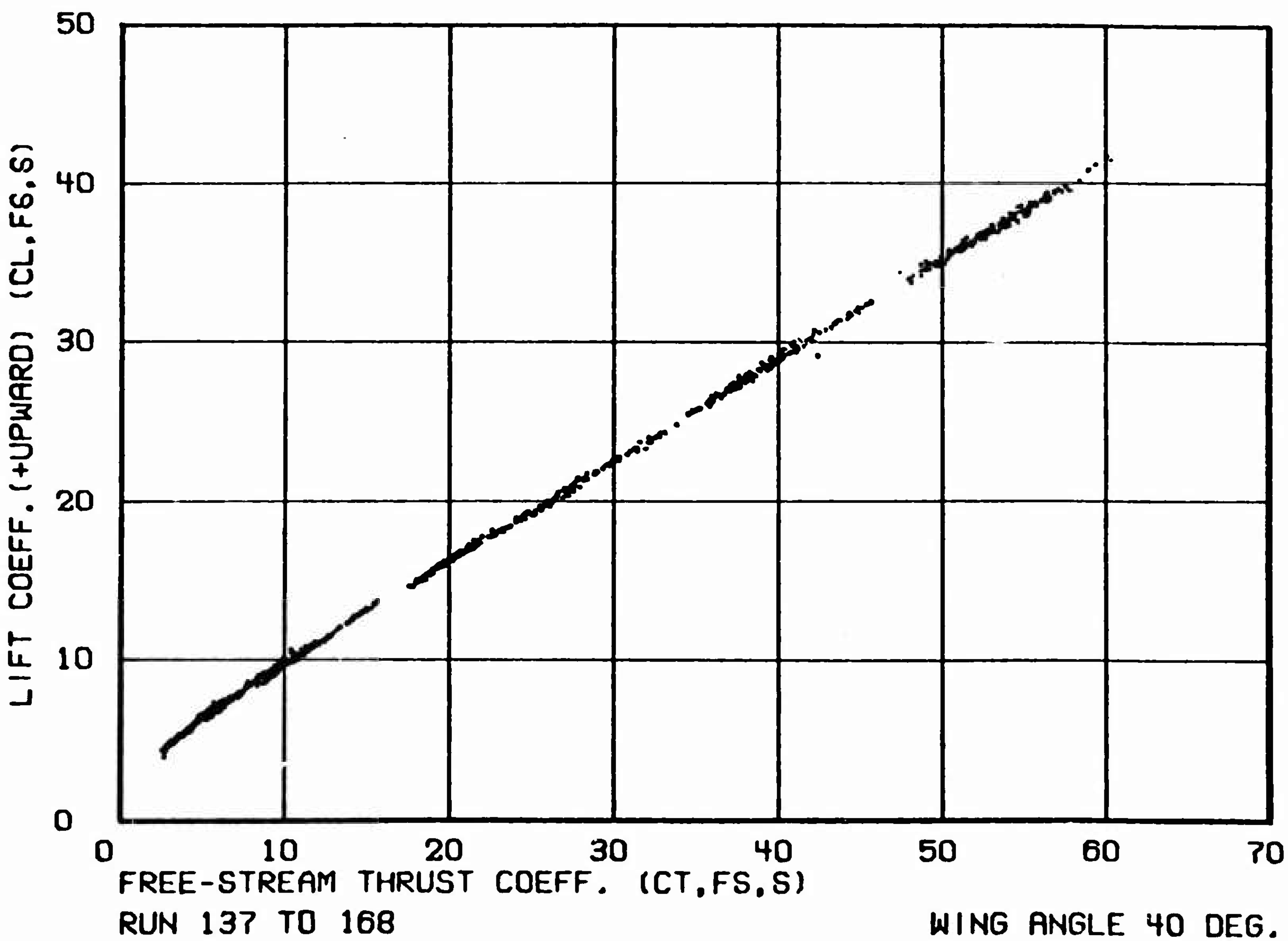

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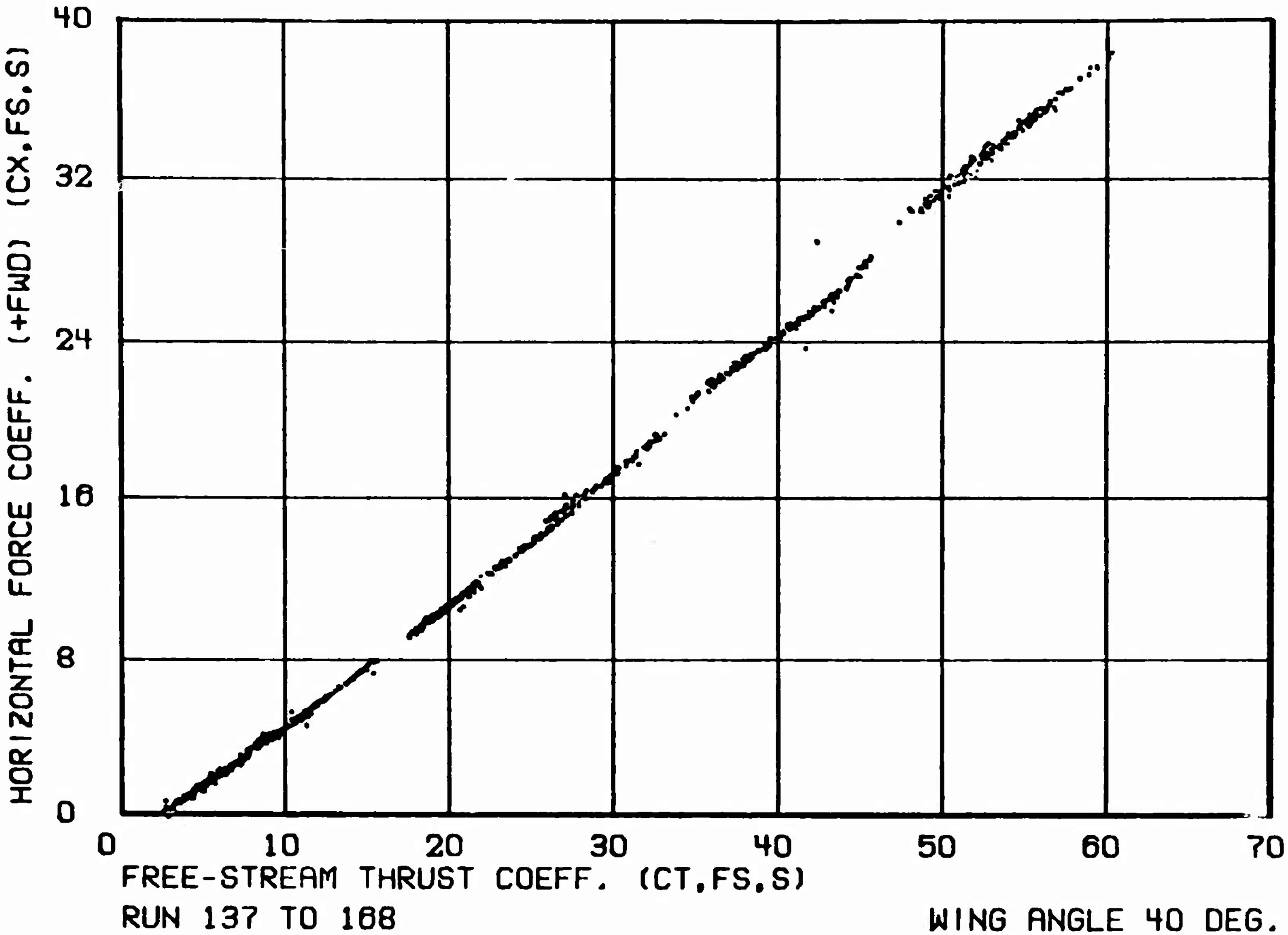

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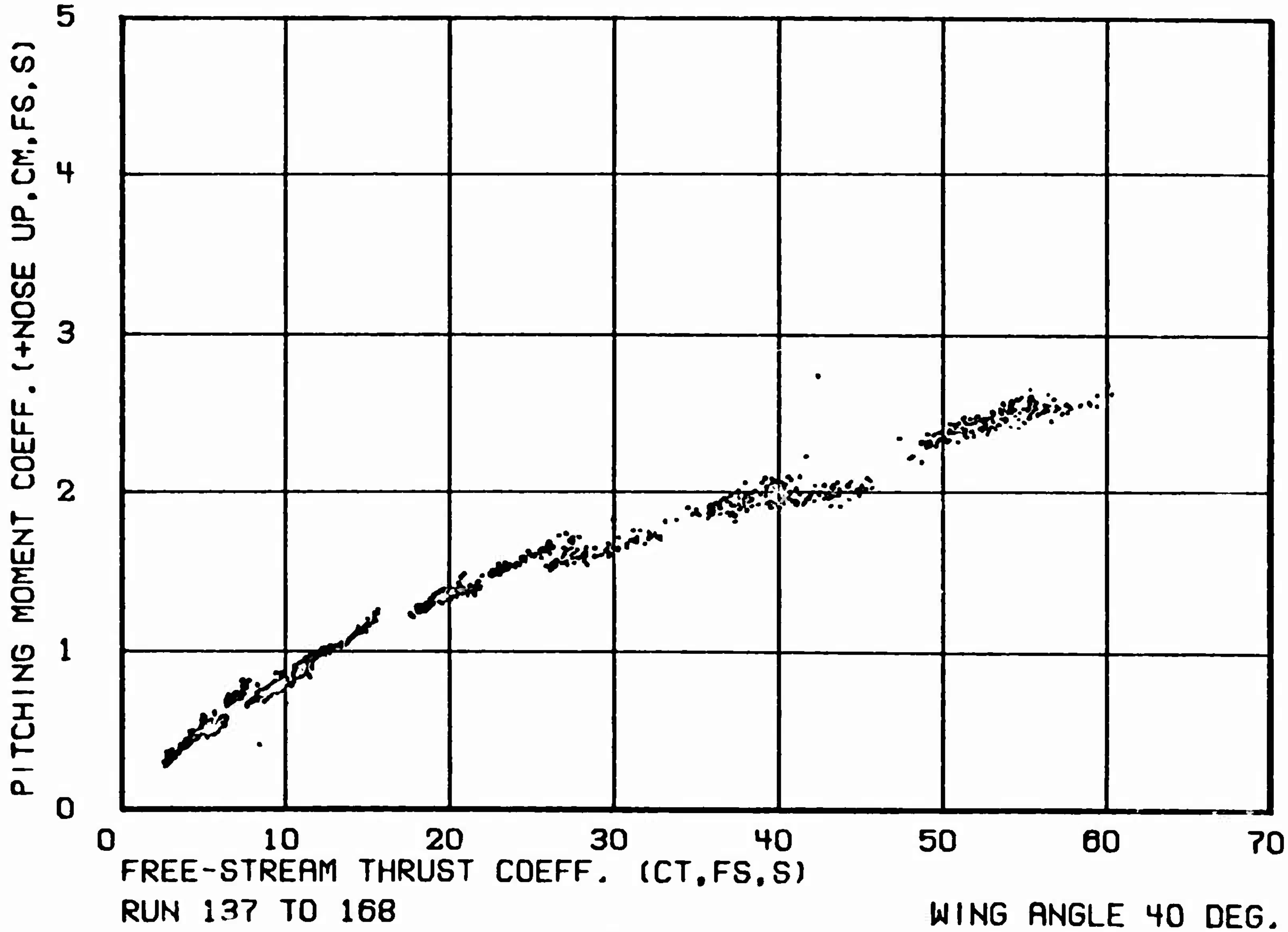

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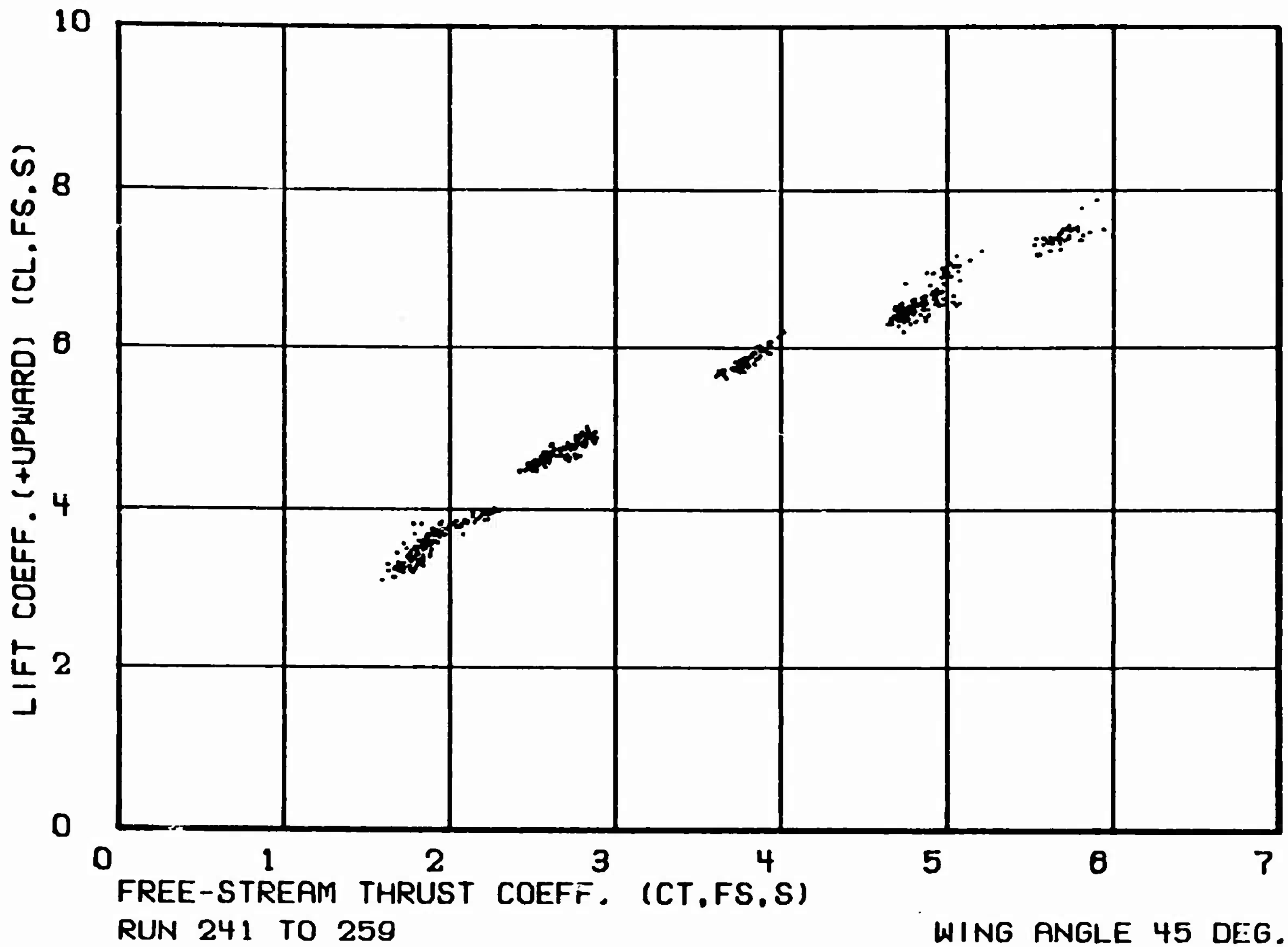

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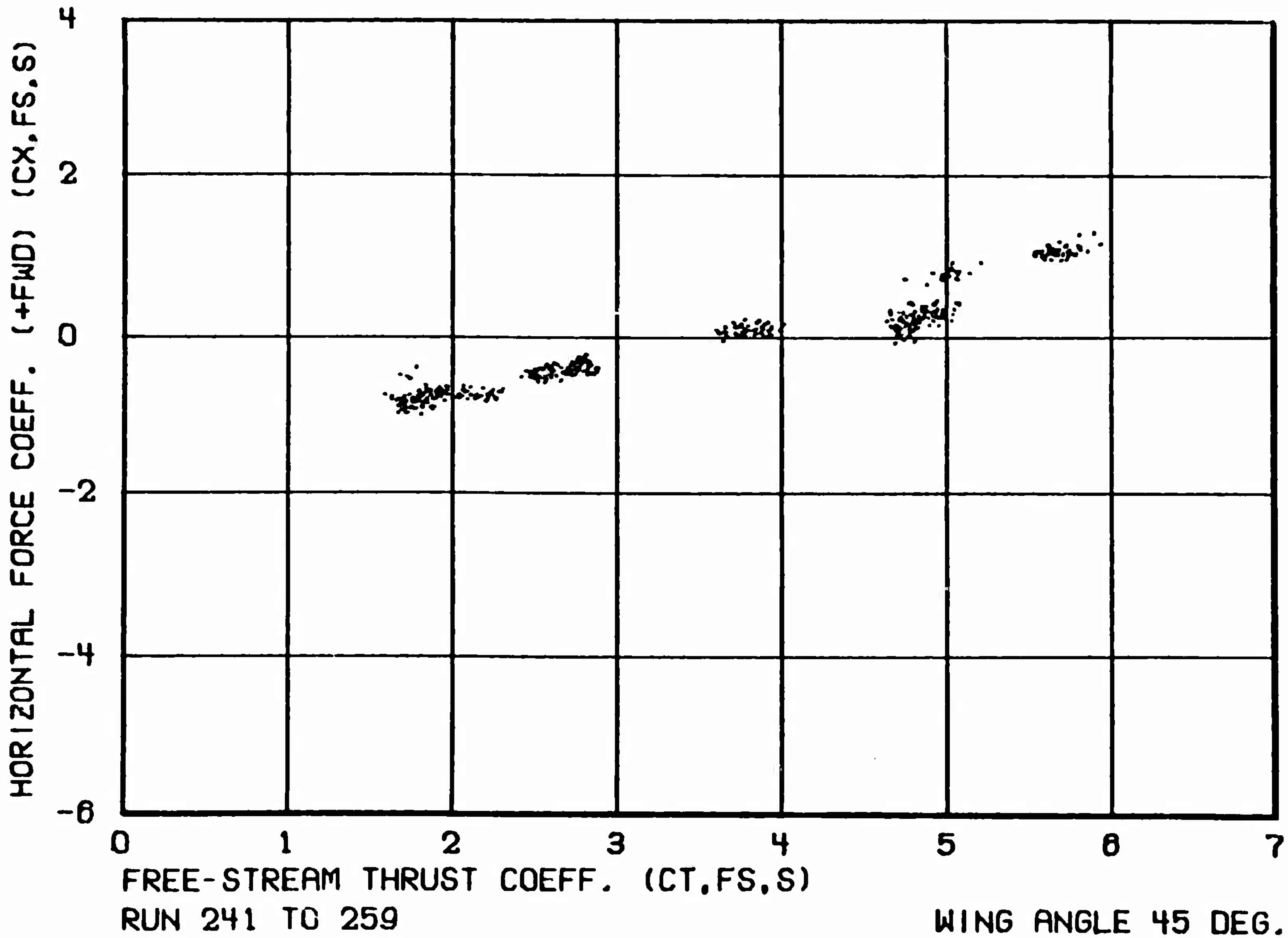

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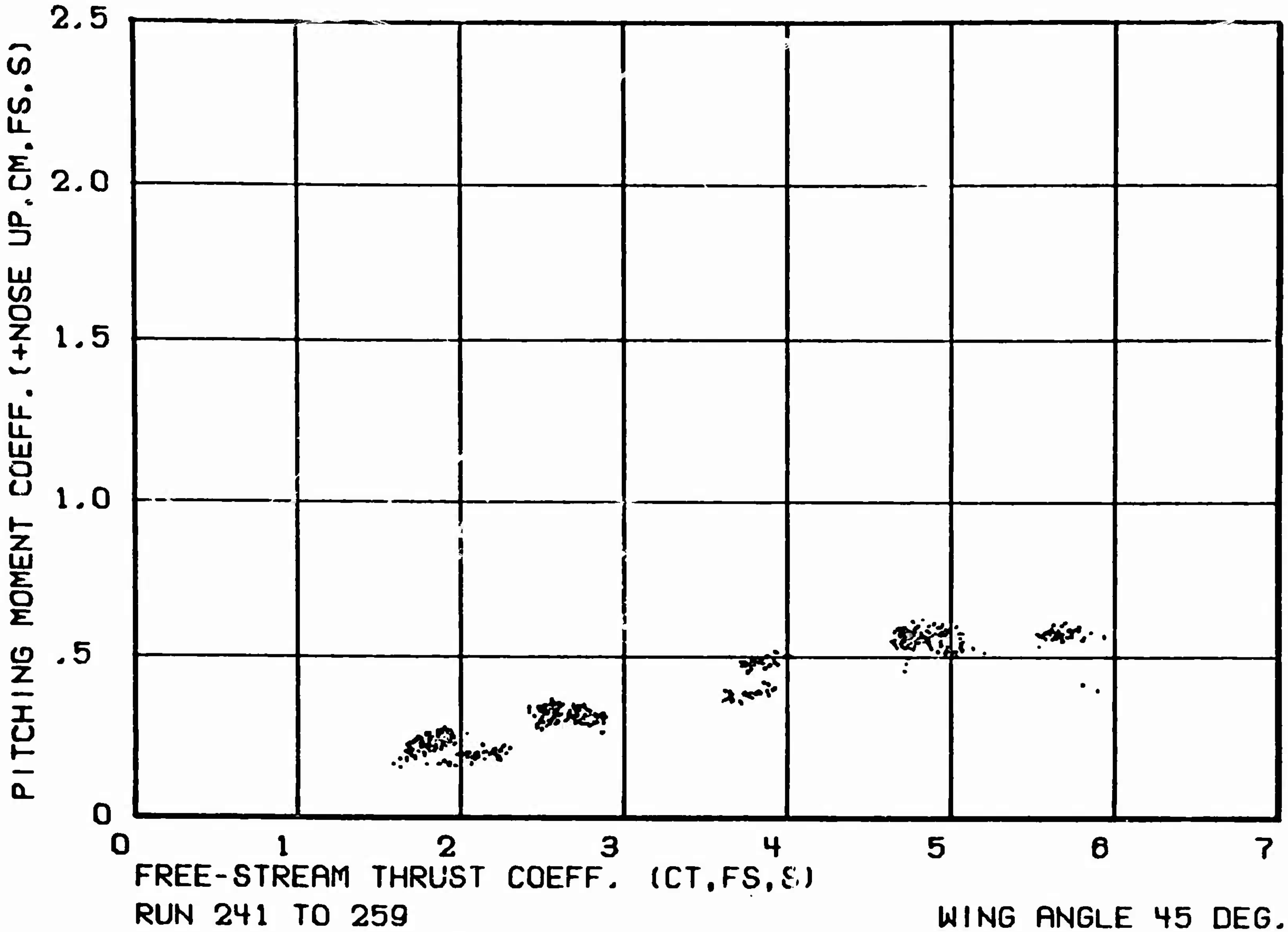

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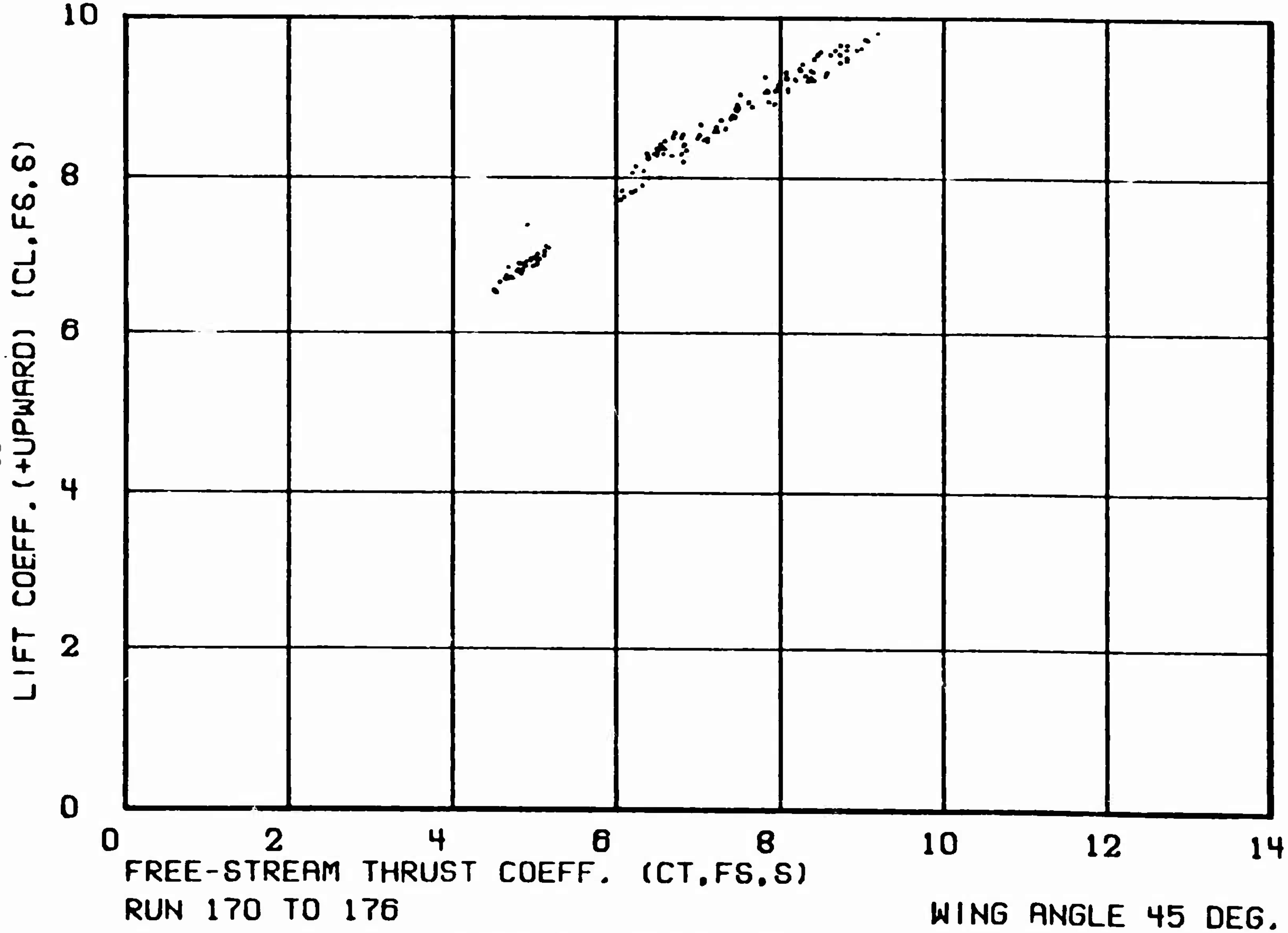

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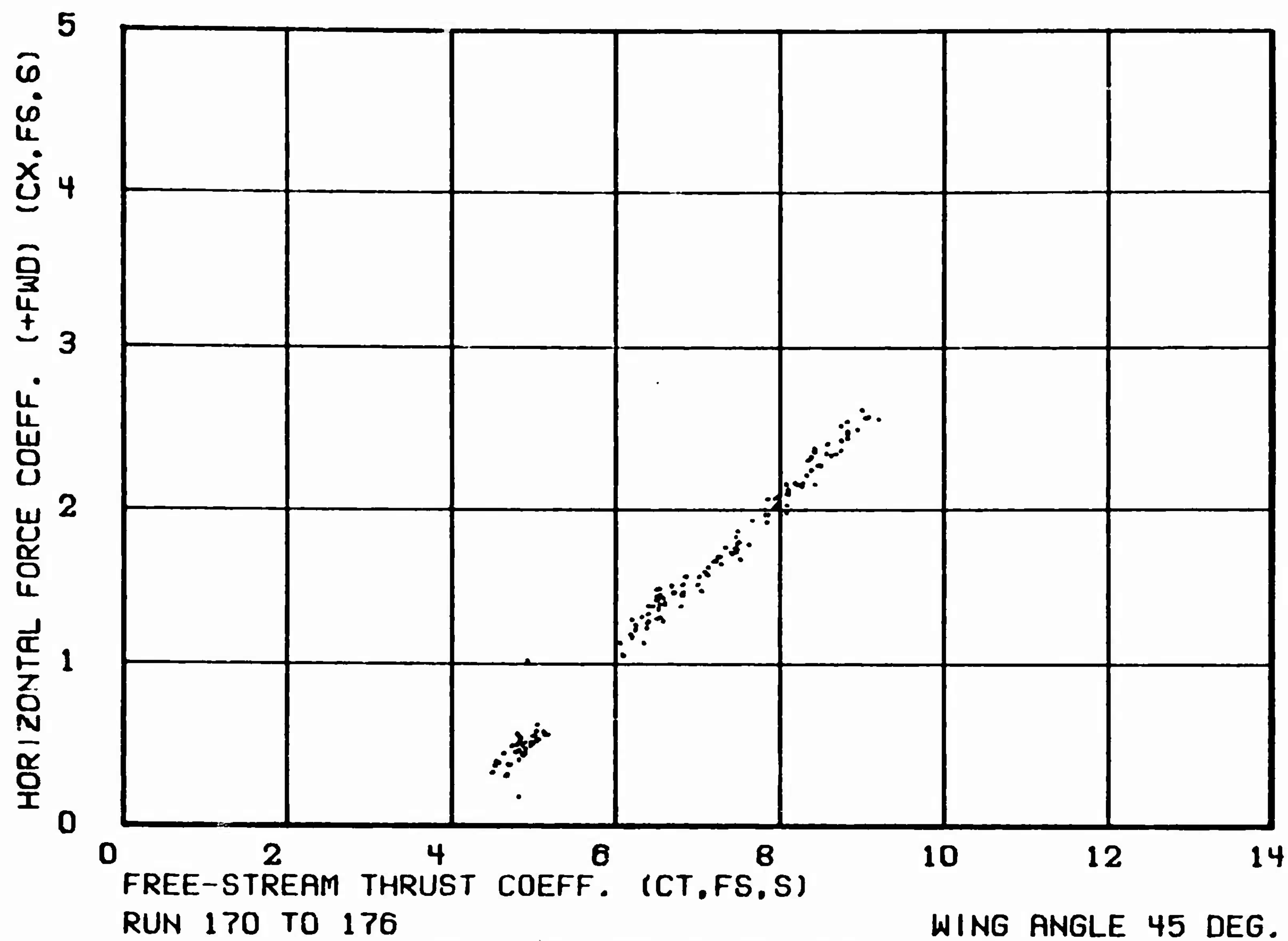

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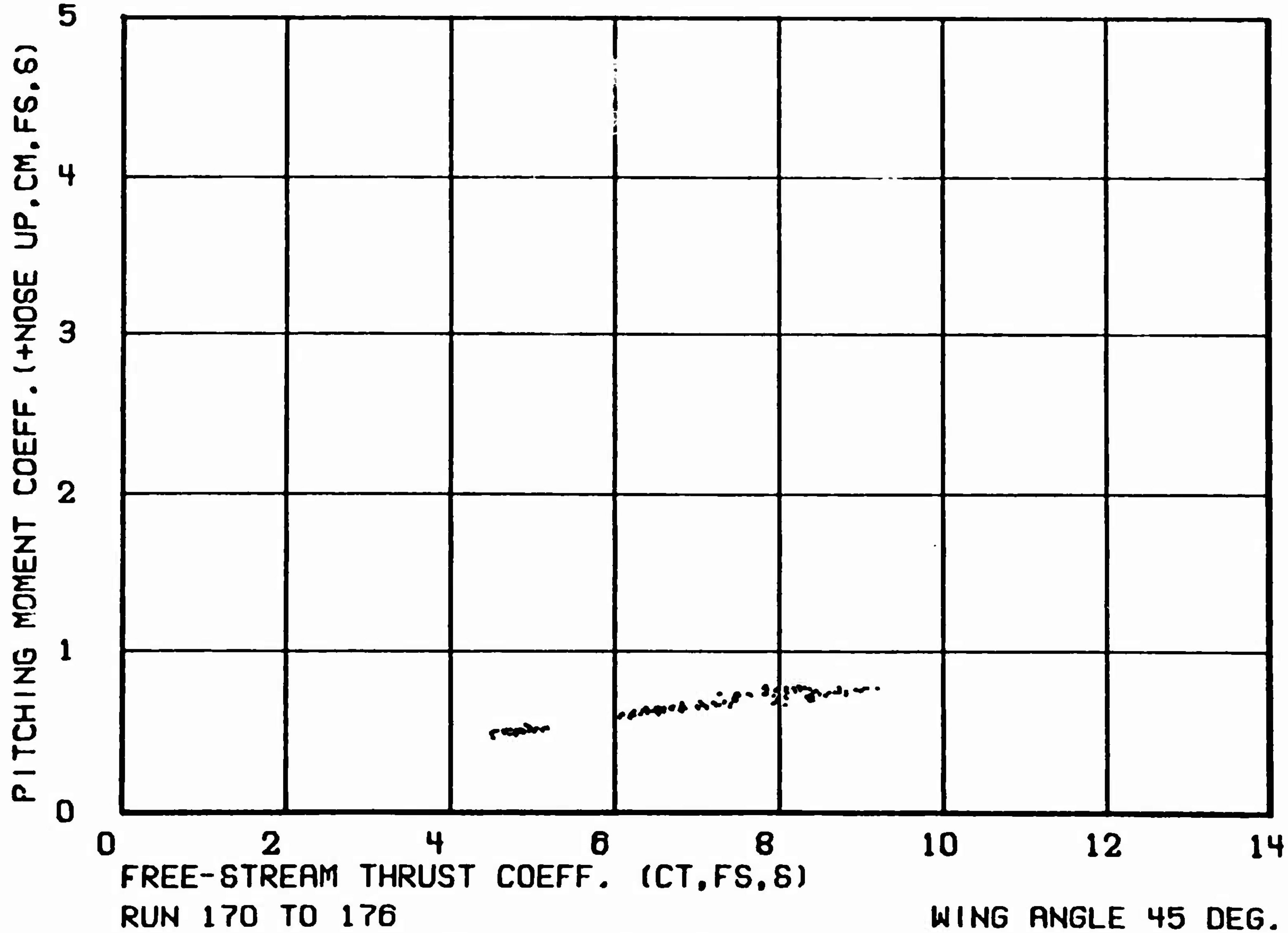

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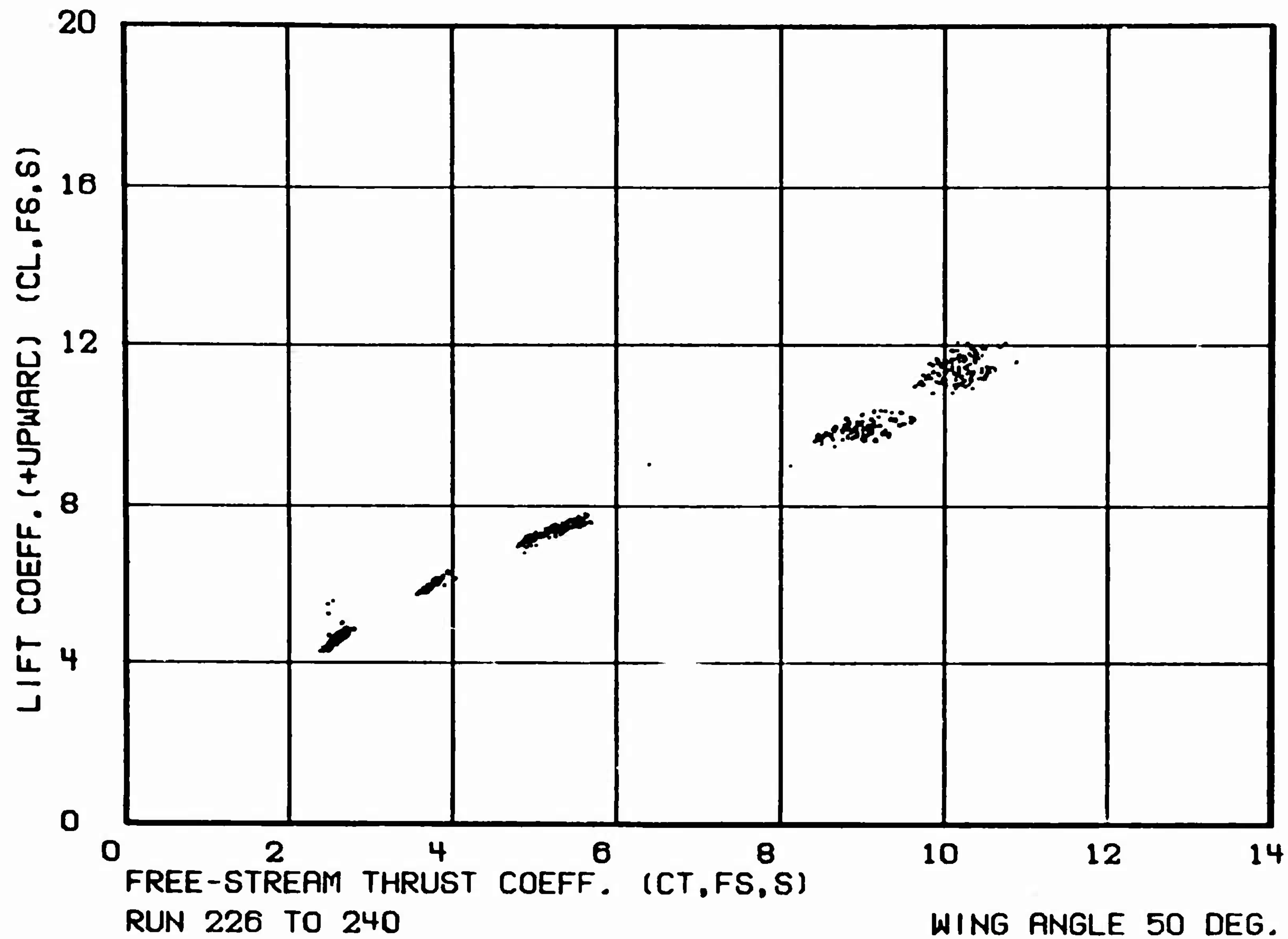

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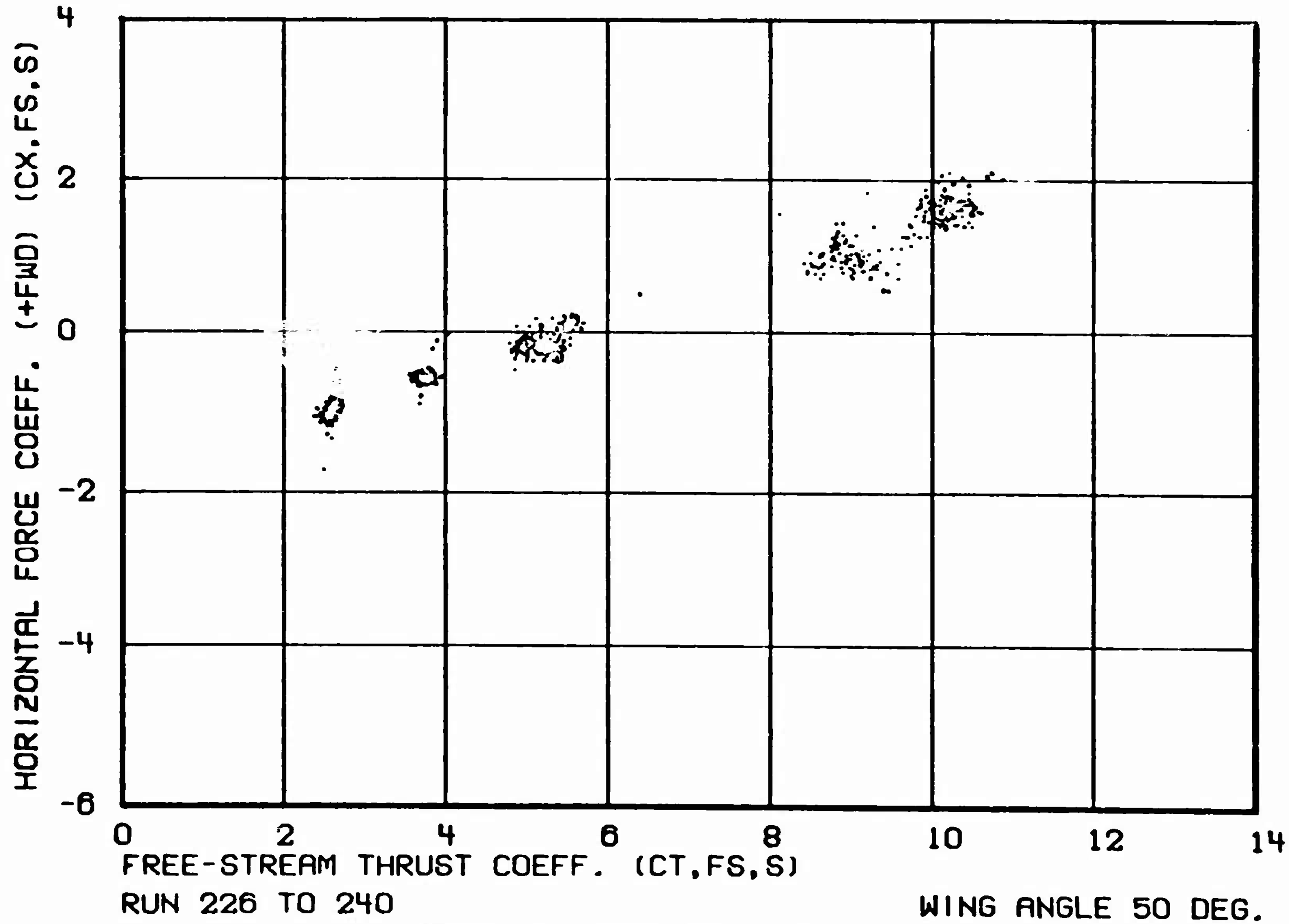

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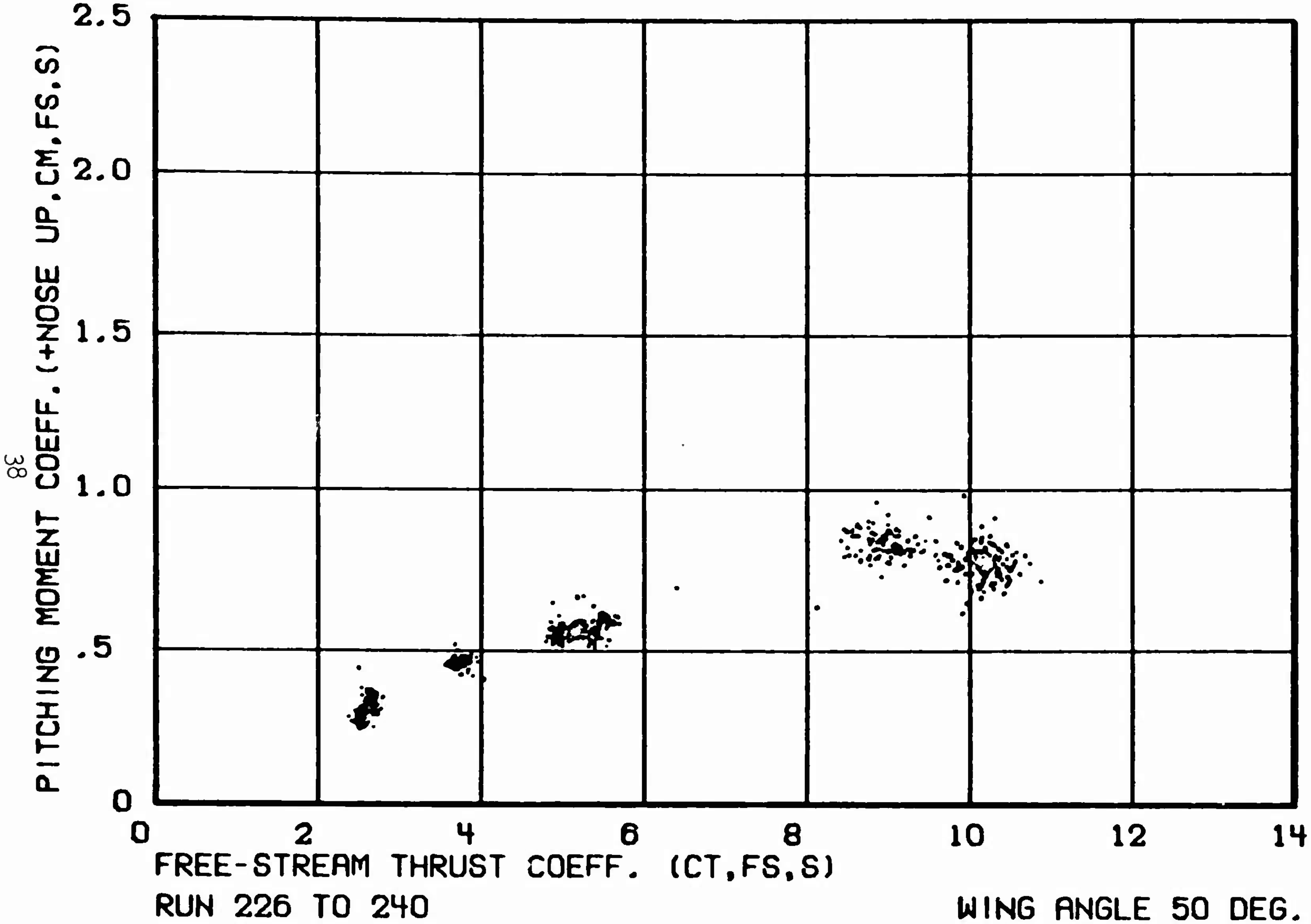

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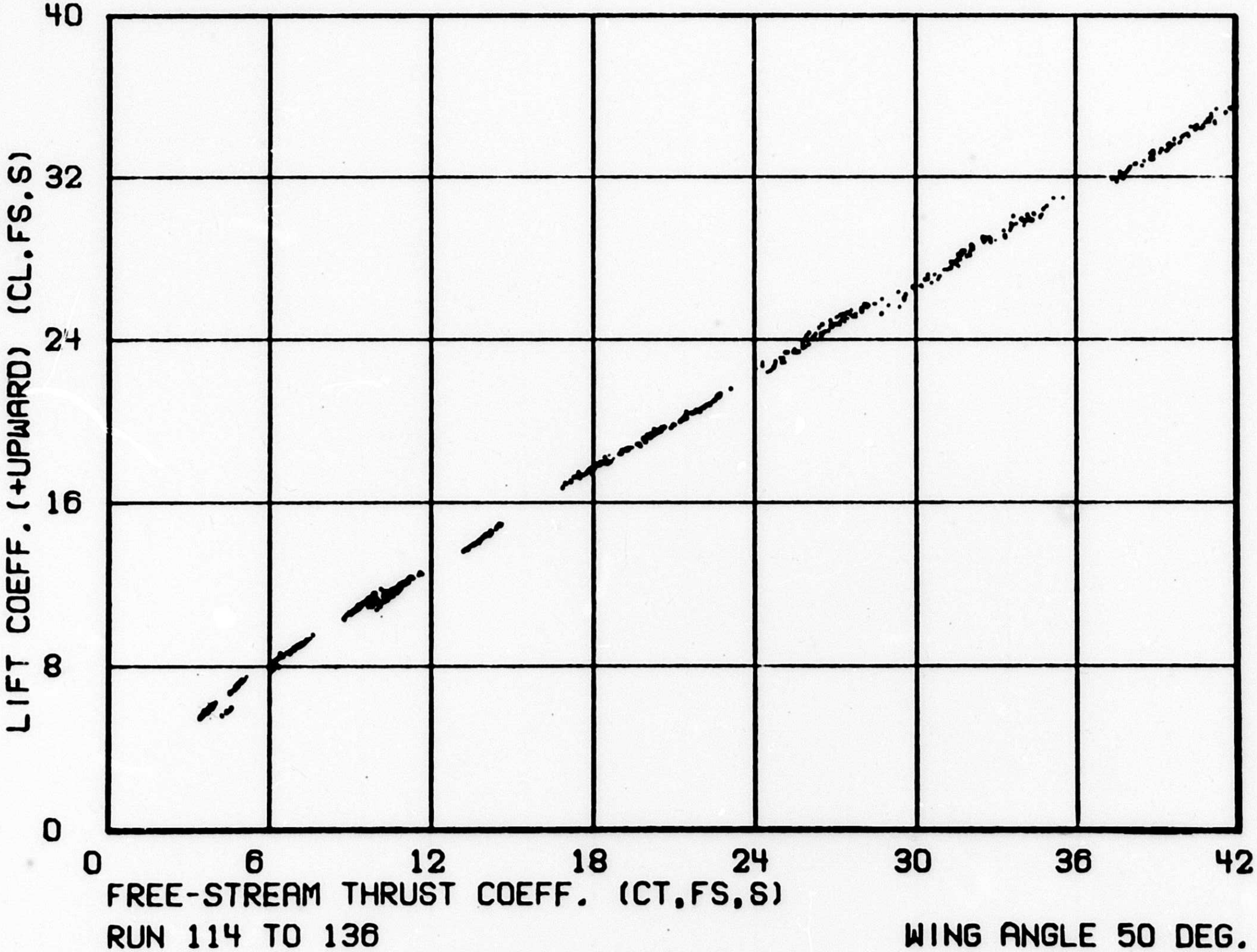

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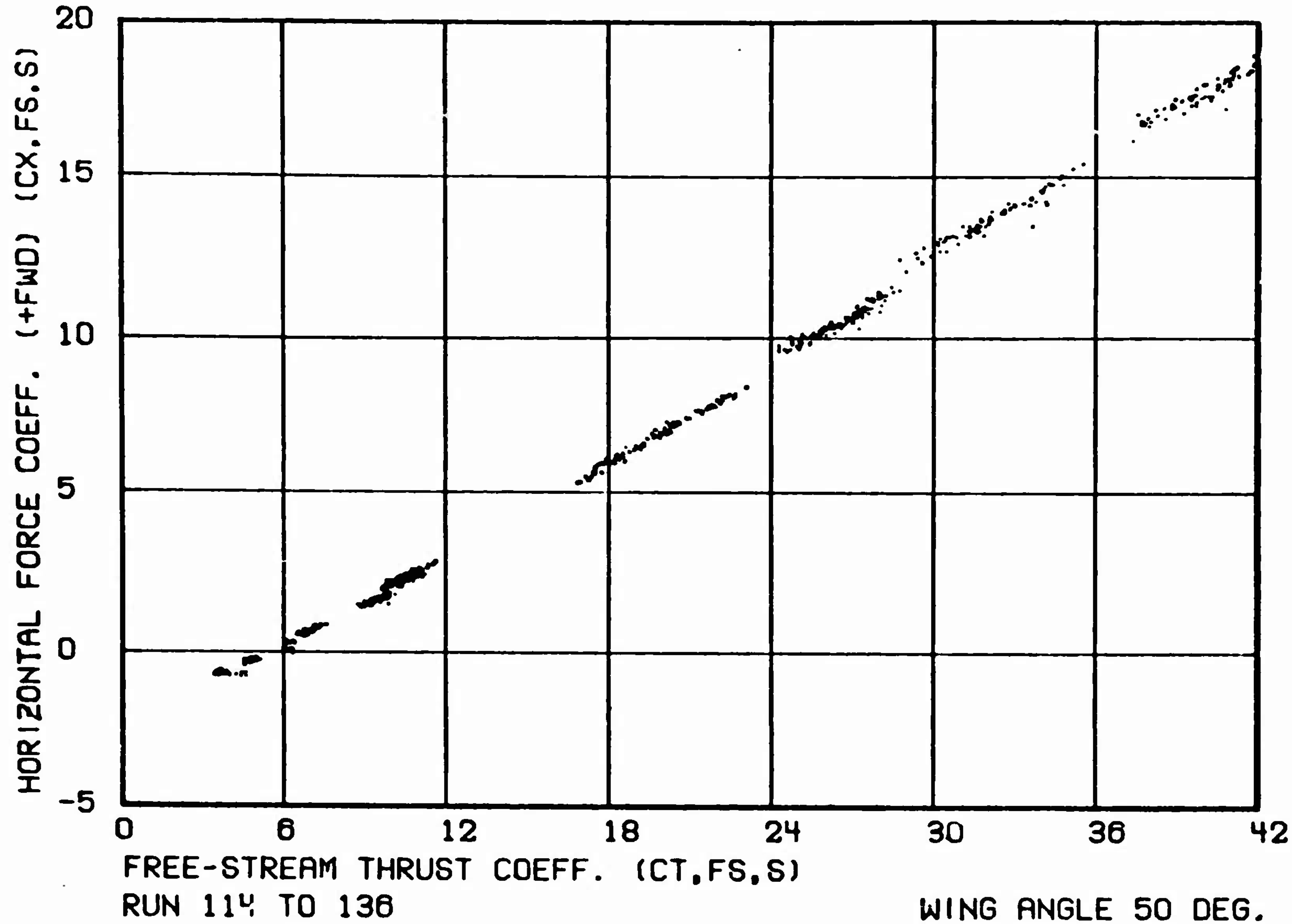

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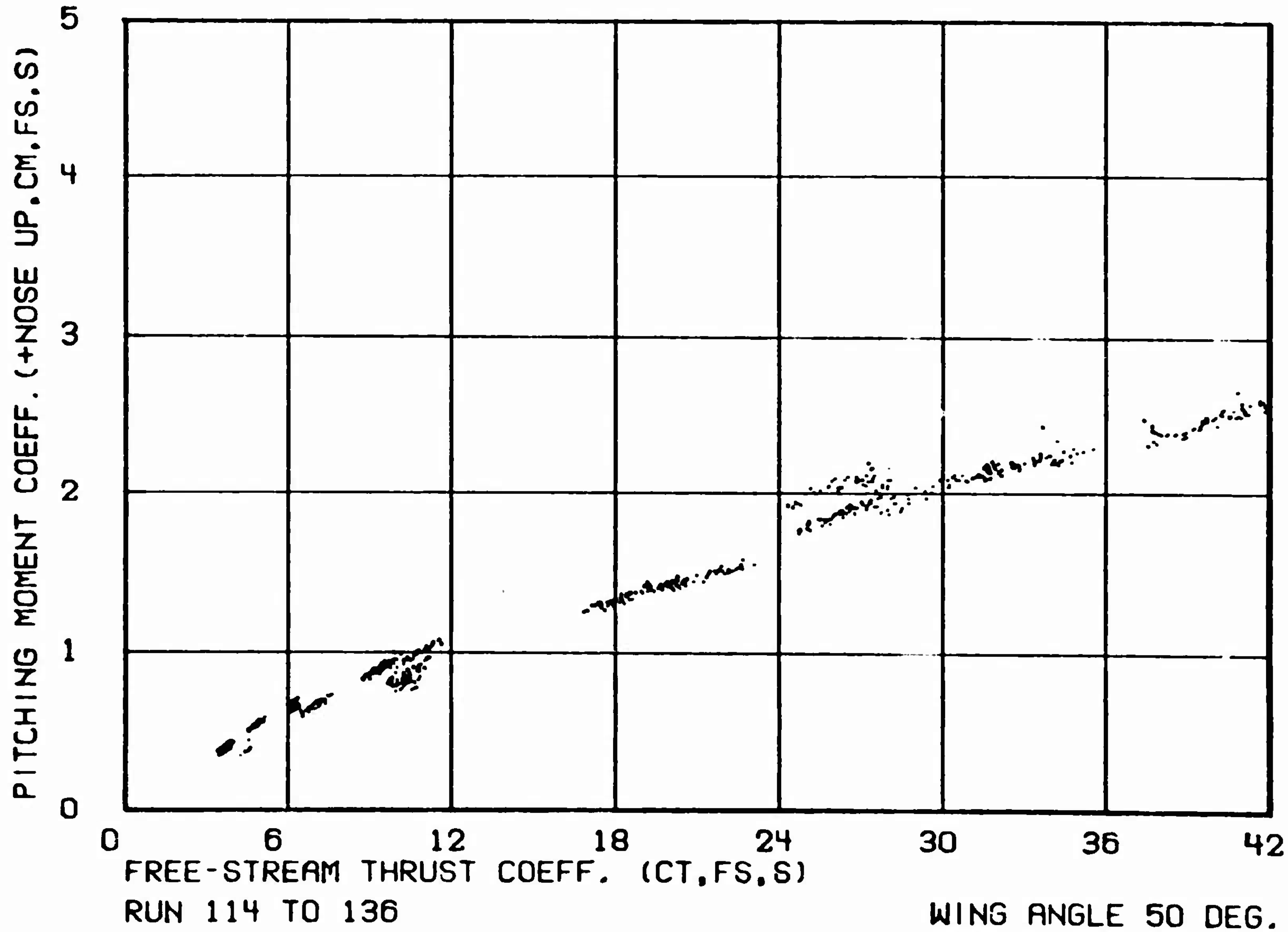

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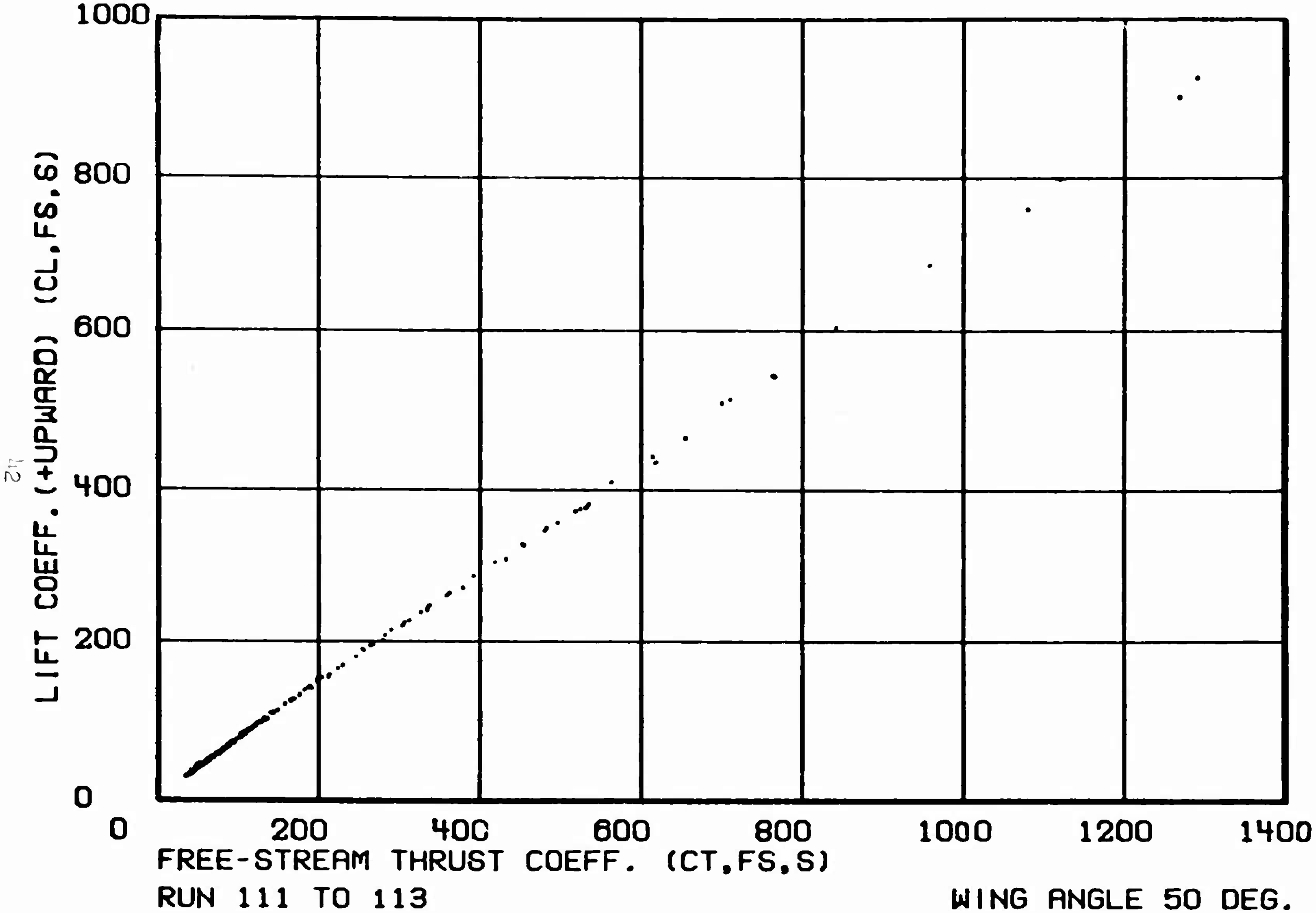

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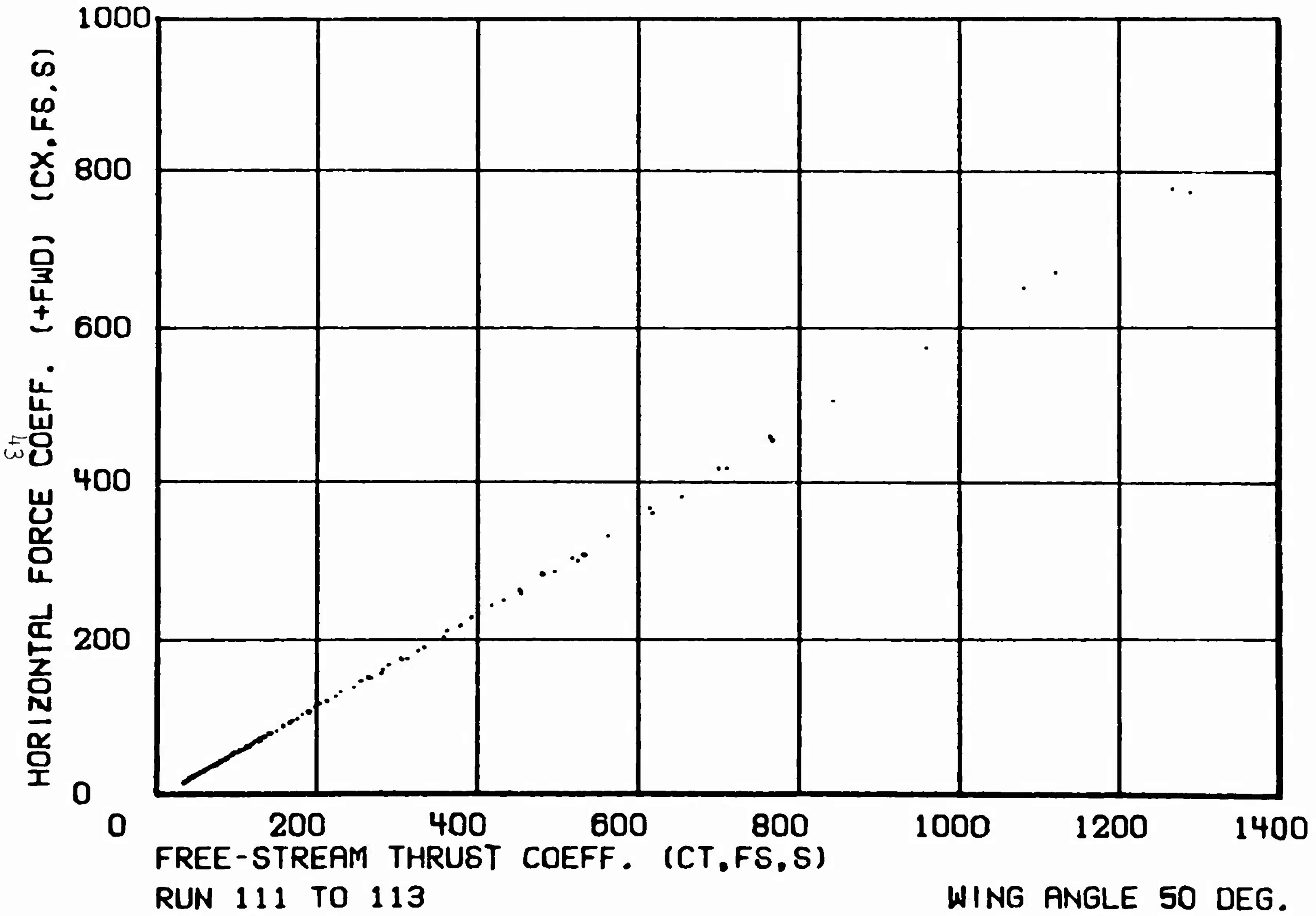

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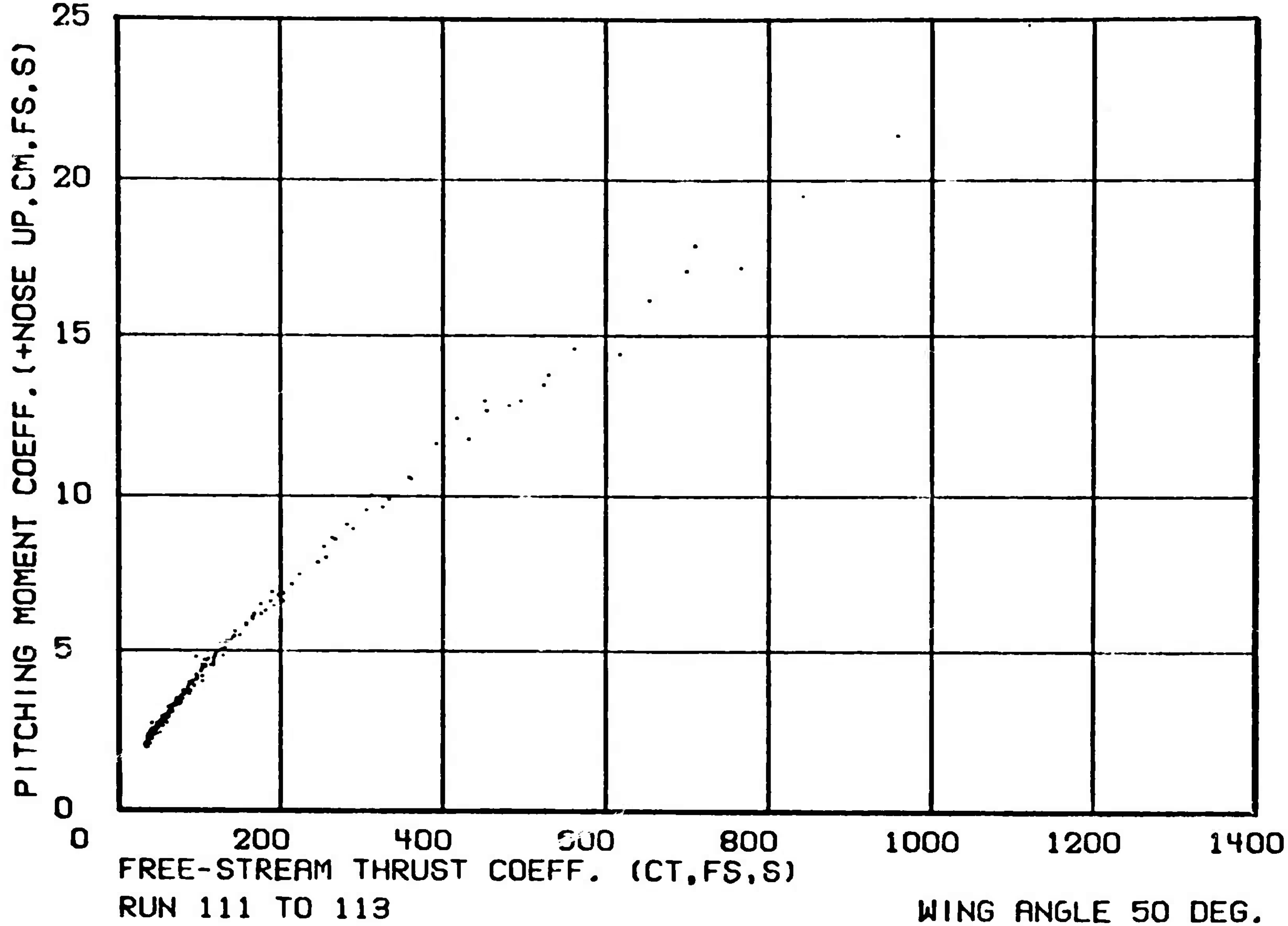

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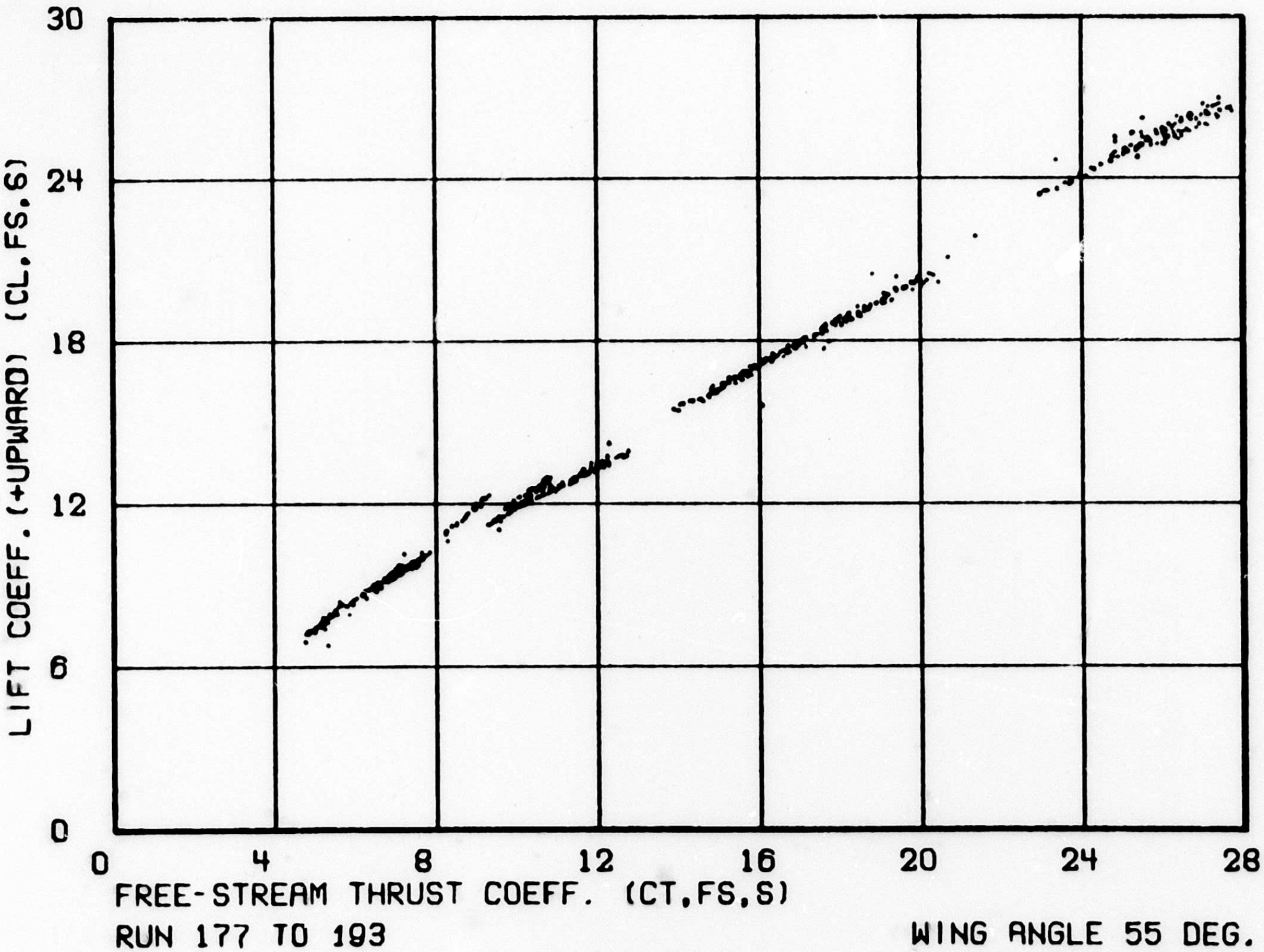
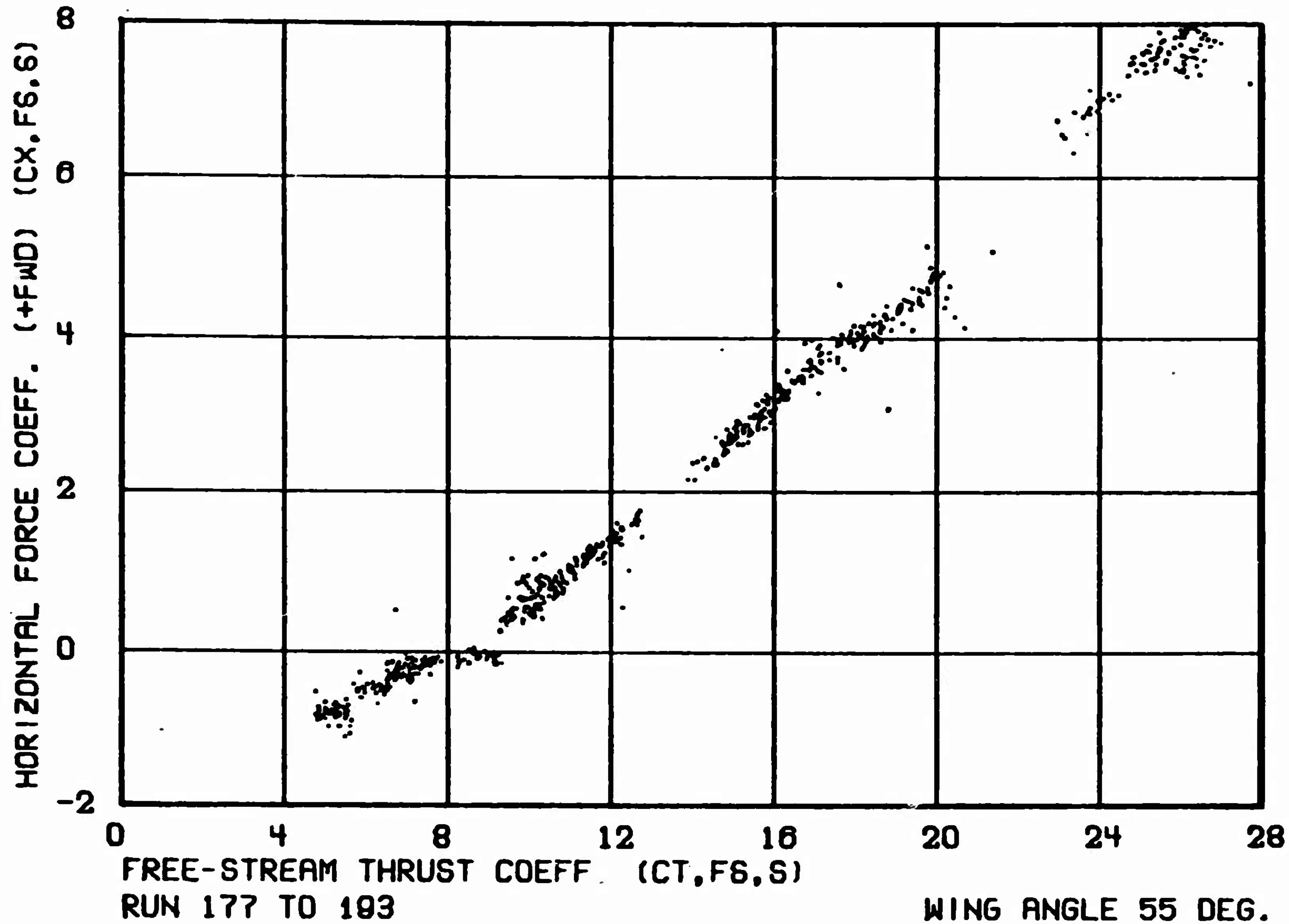


Figure 18a. Propeller-Wing Data



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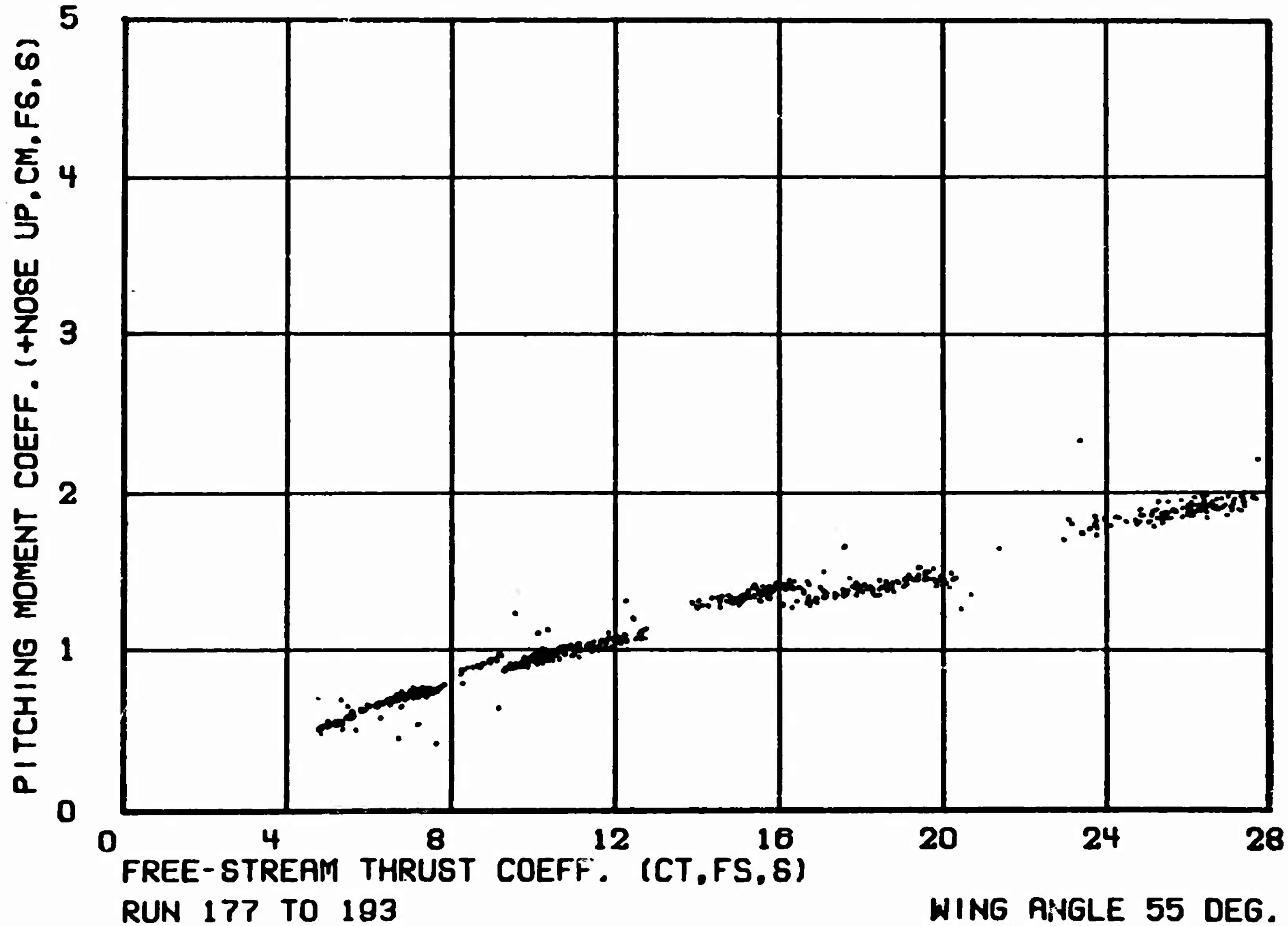

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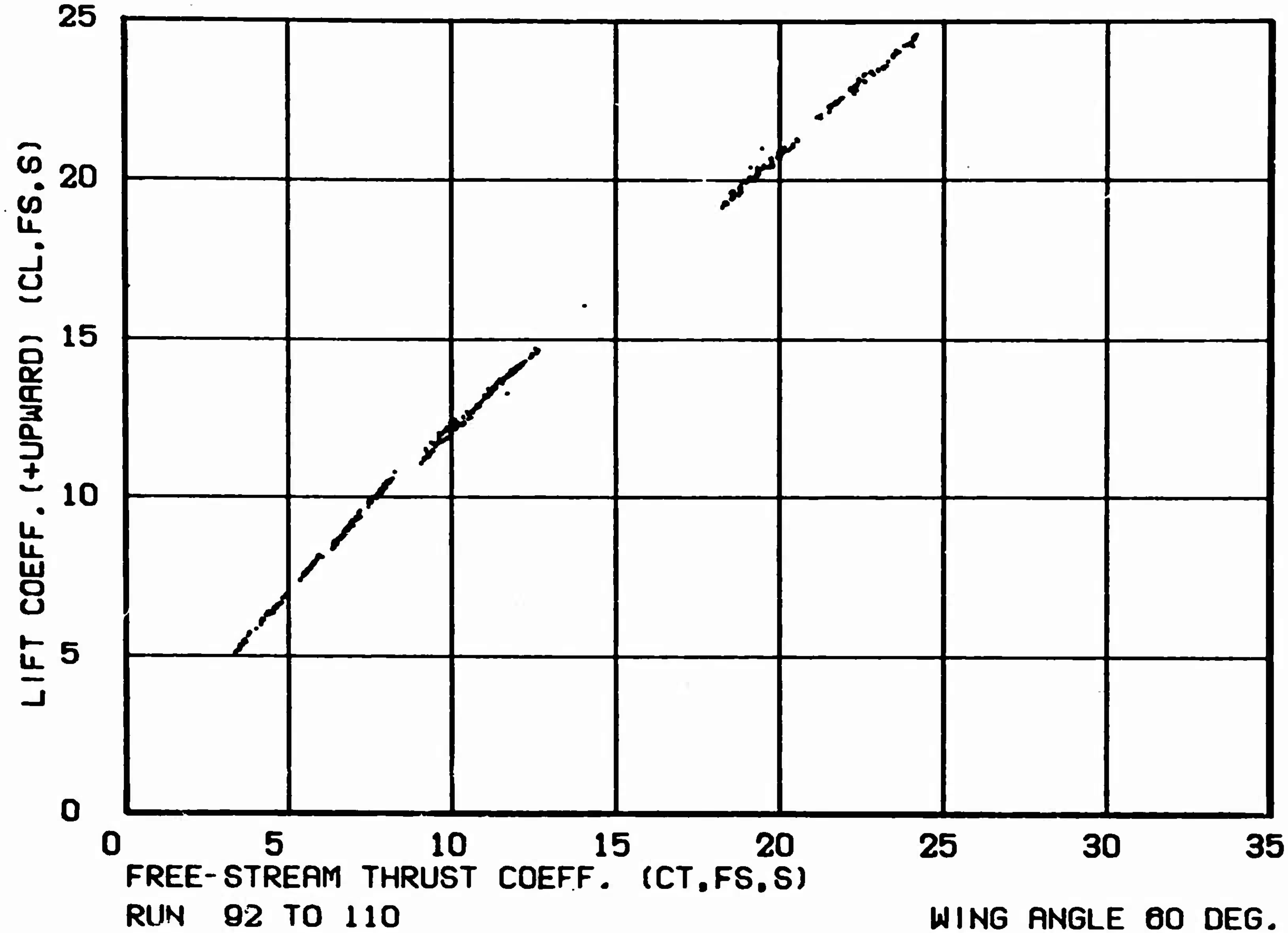
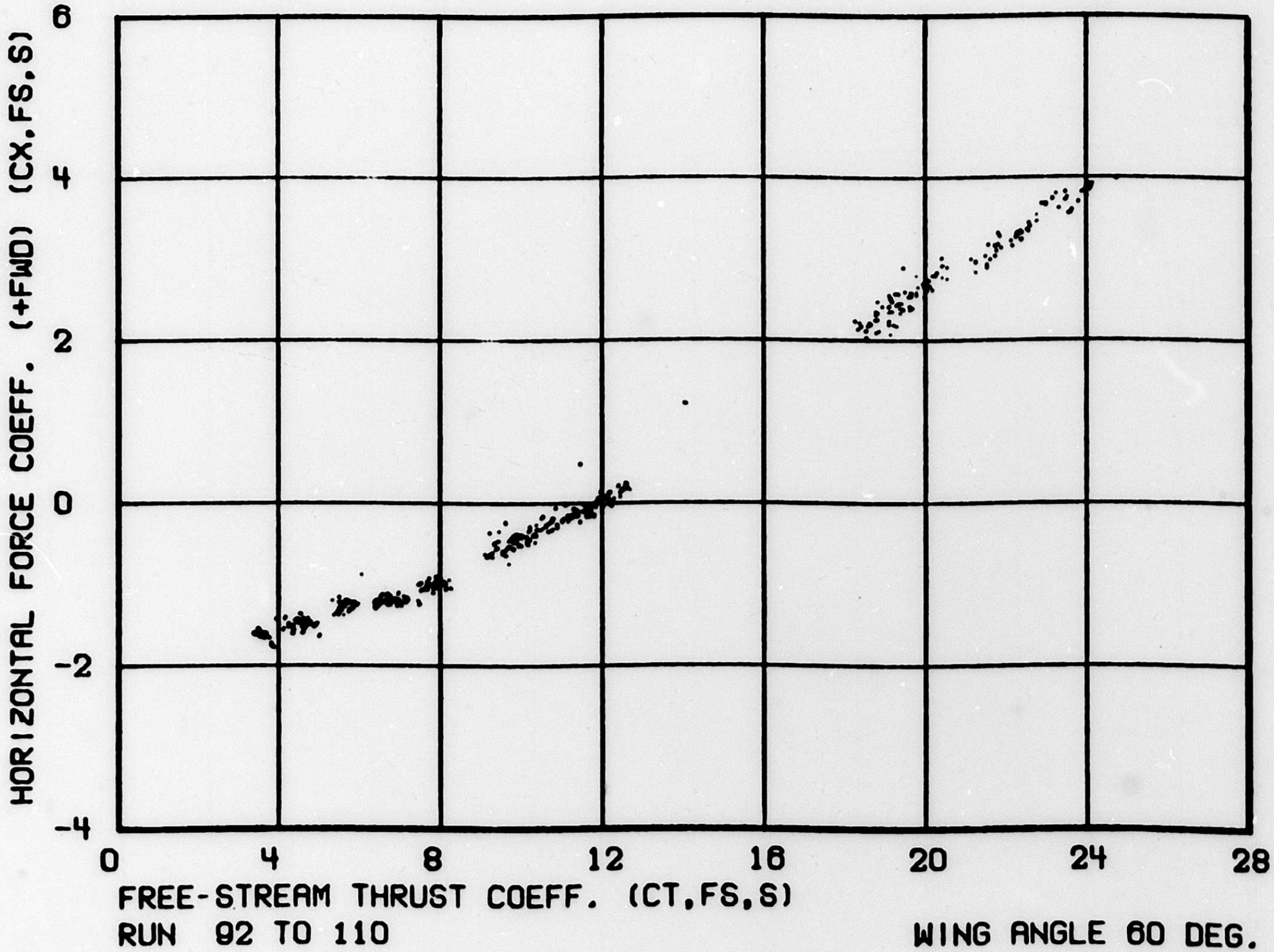


Figure 19a. Propeller-Wing Data



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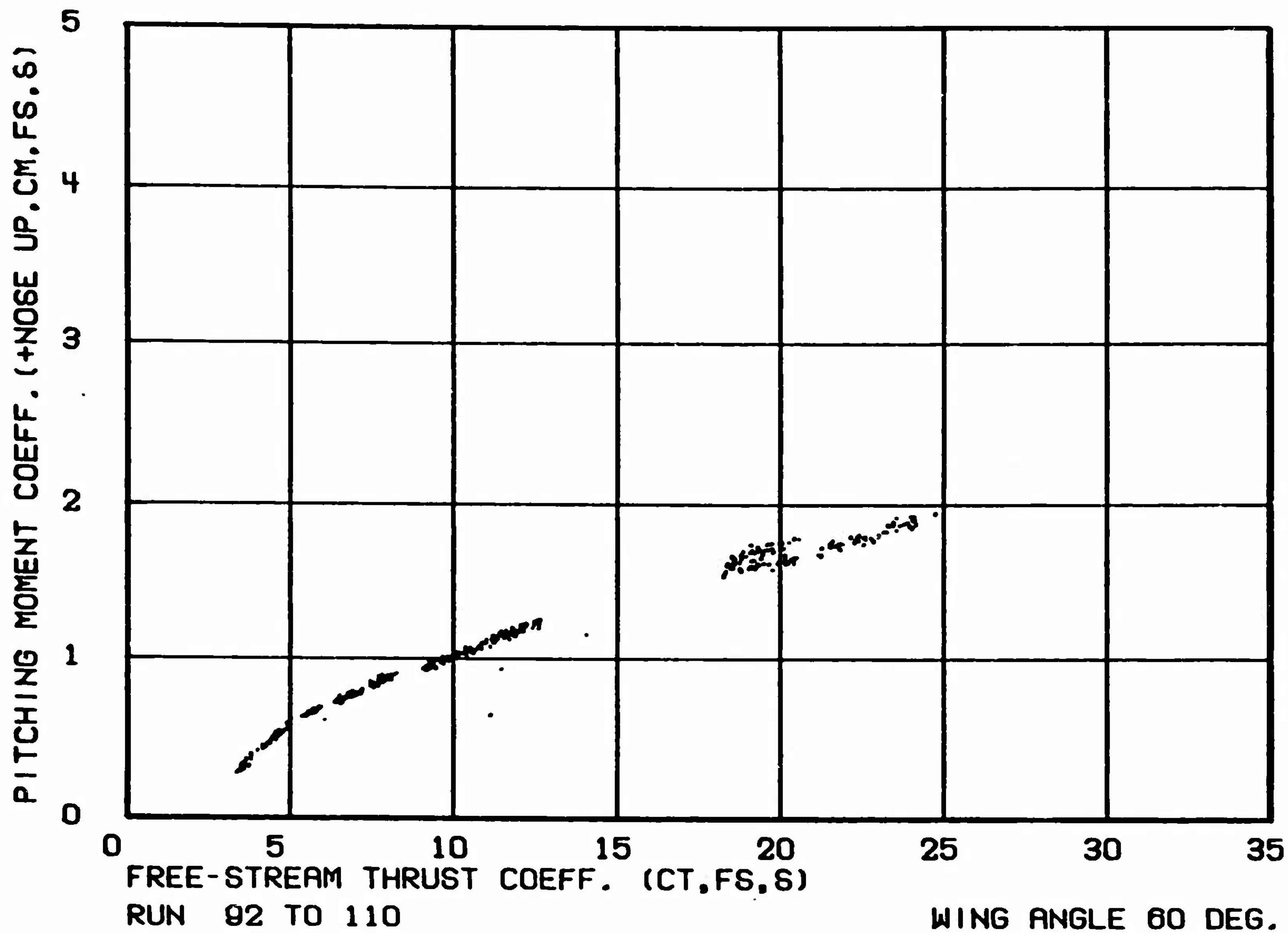
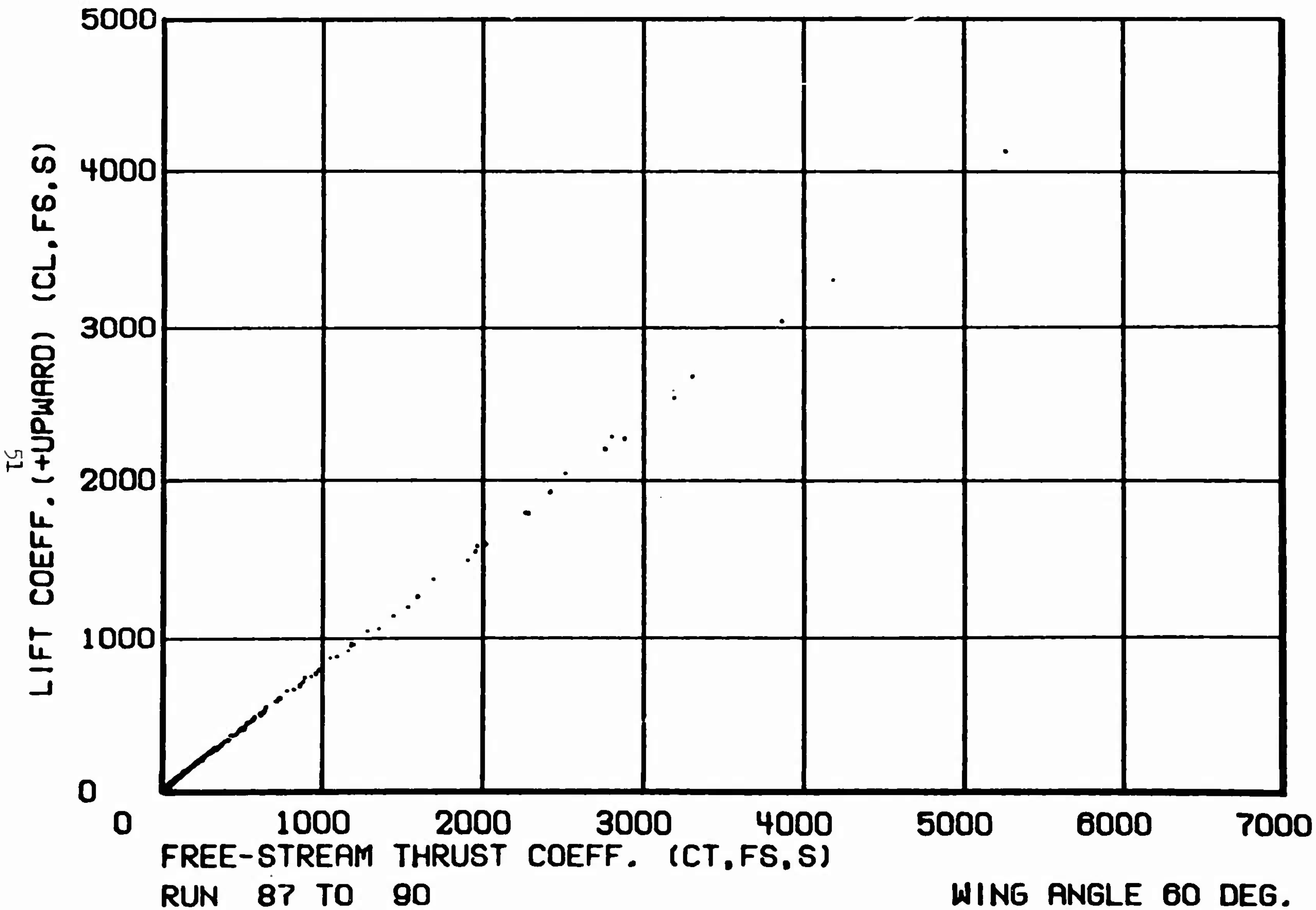


Figure 19c. Propeller-Wing Data



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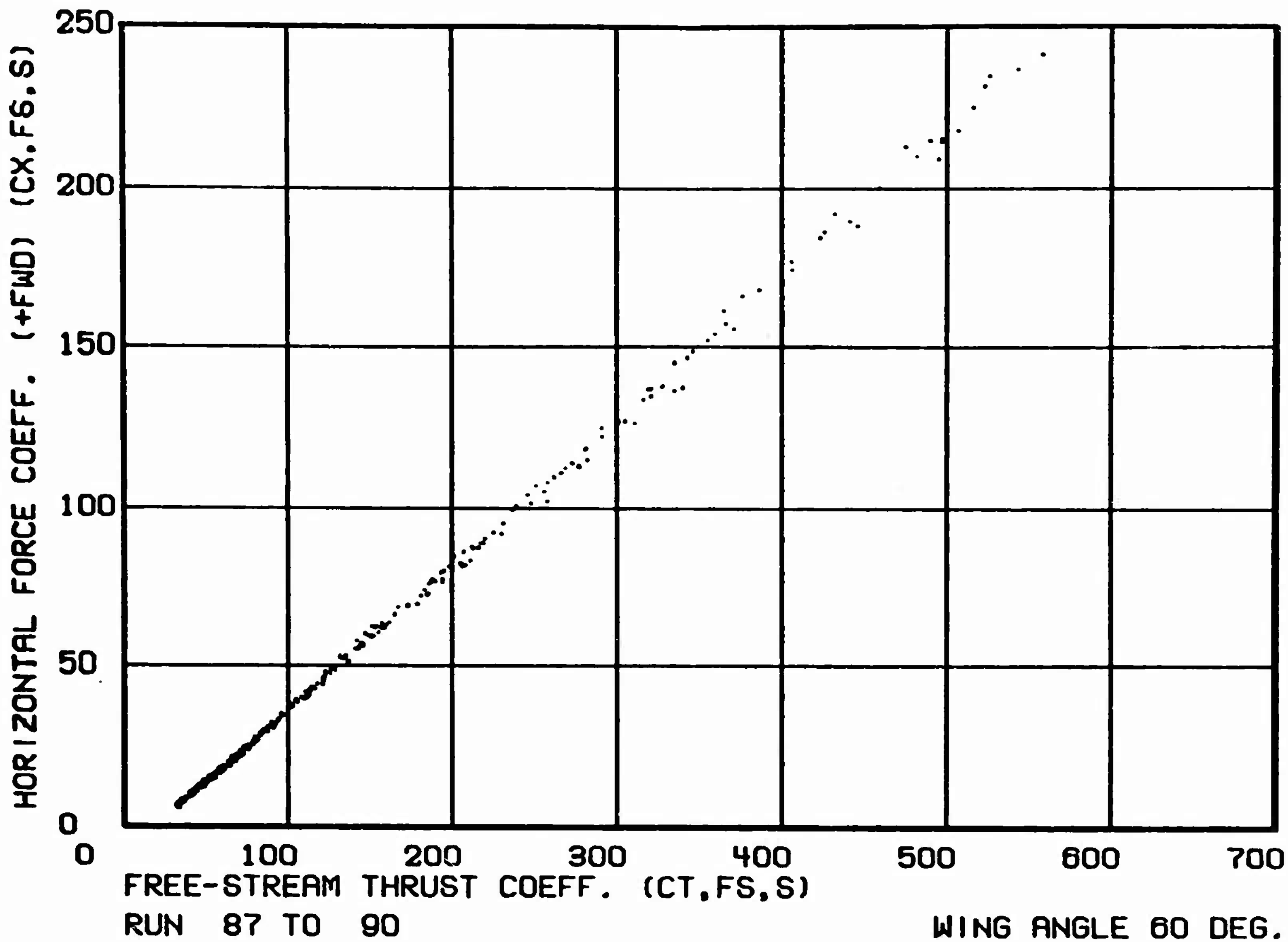

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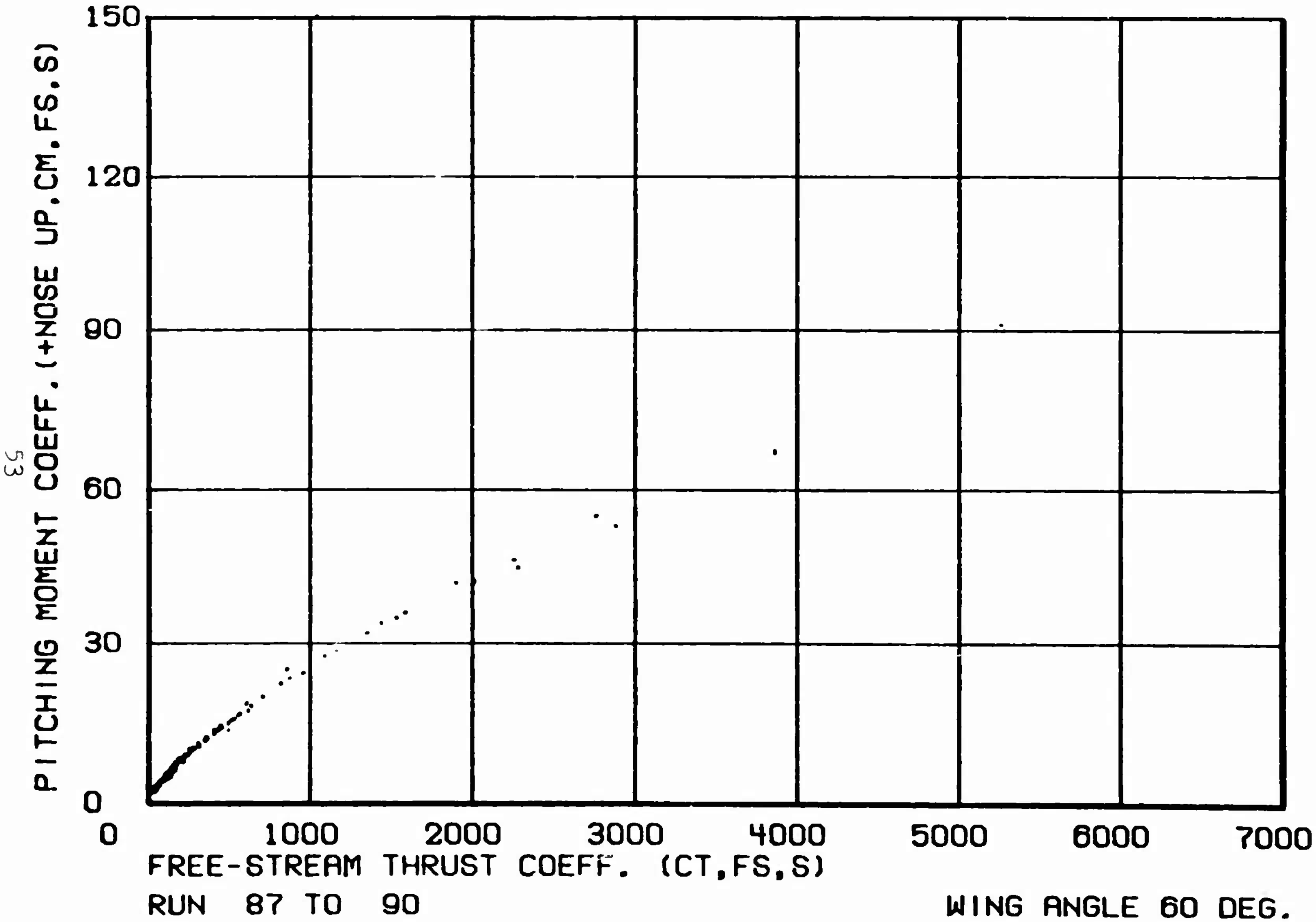

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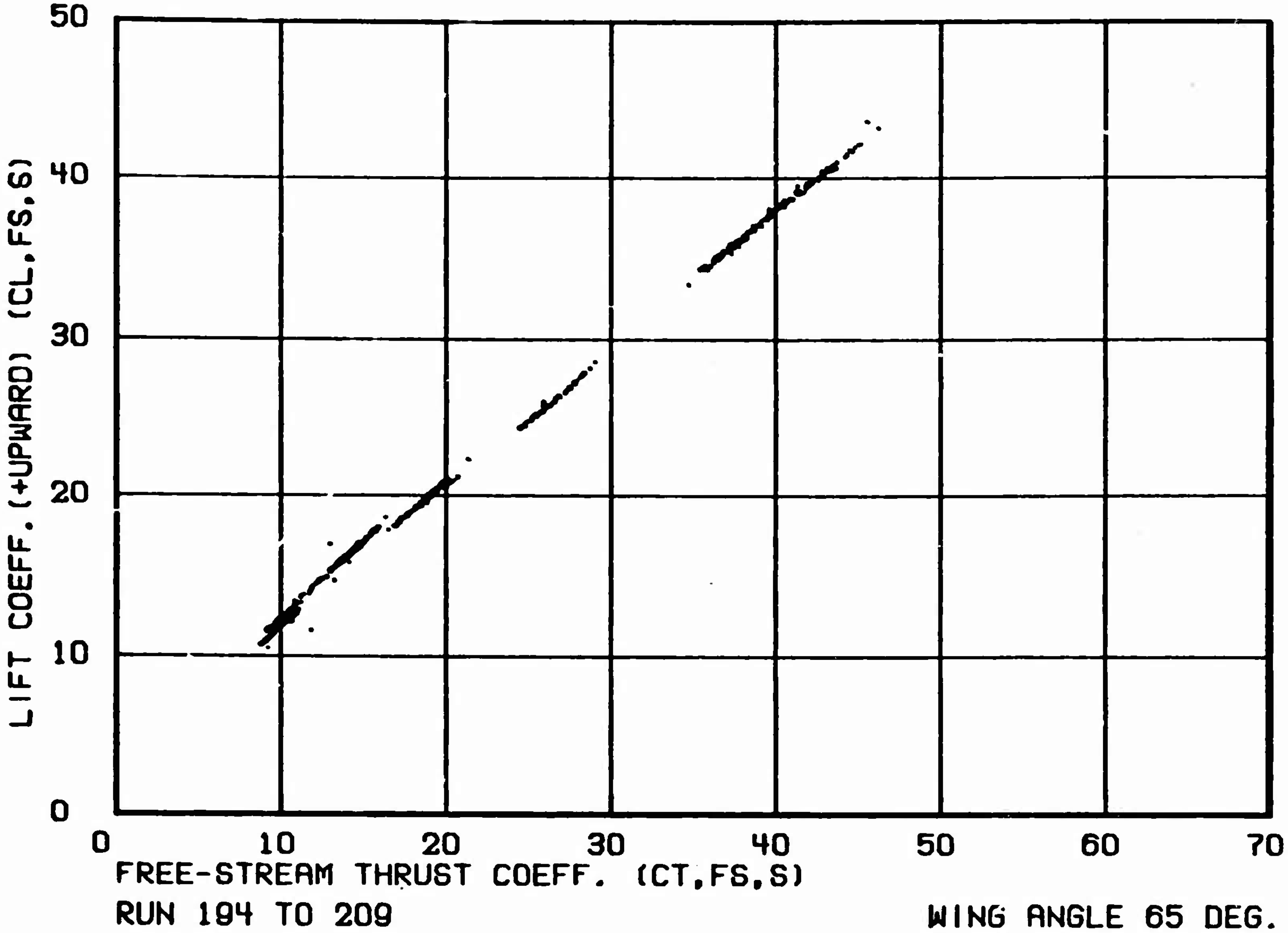

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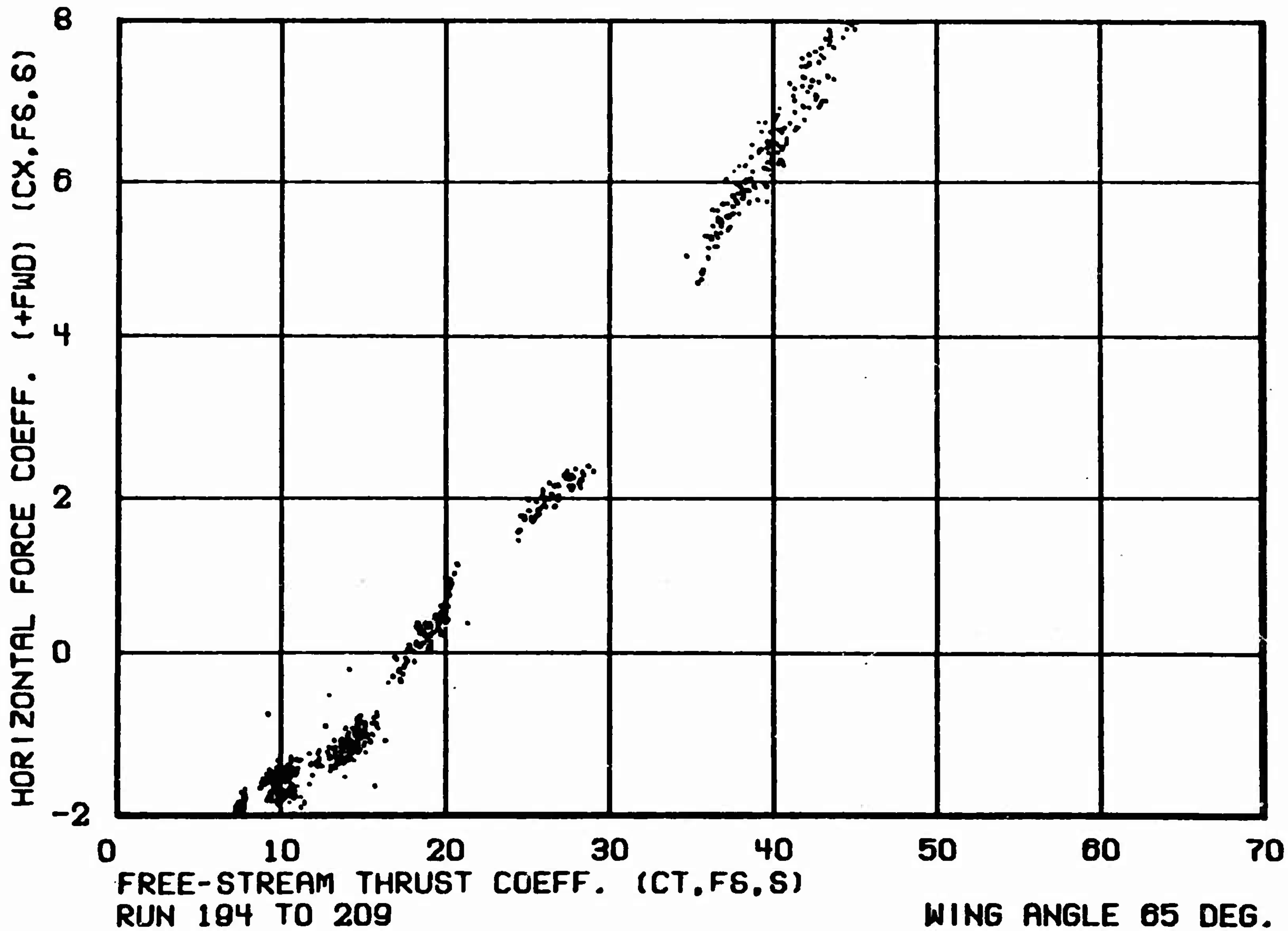

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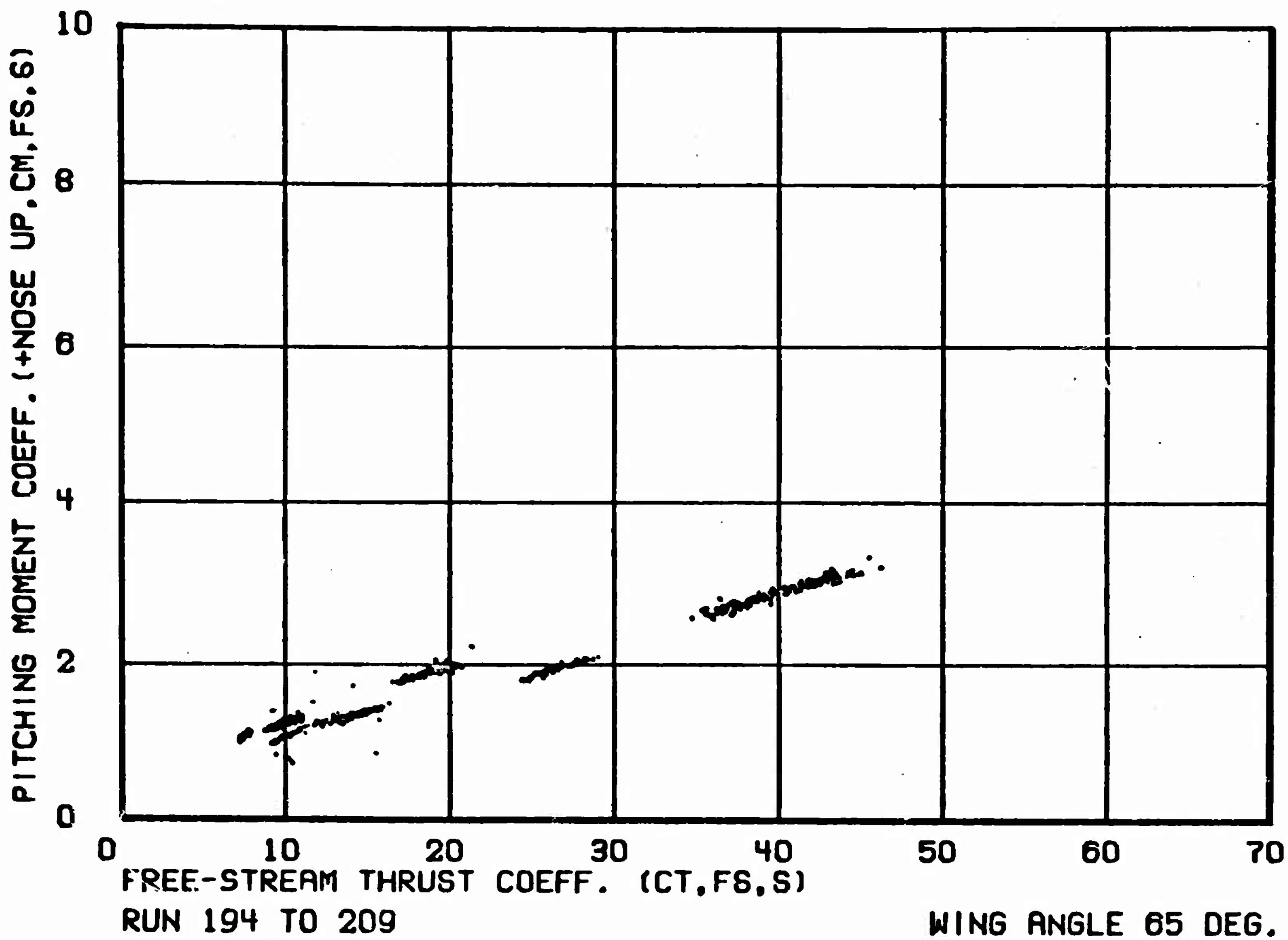

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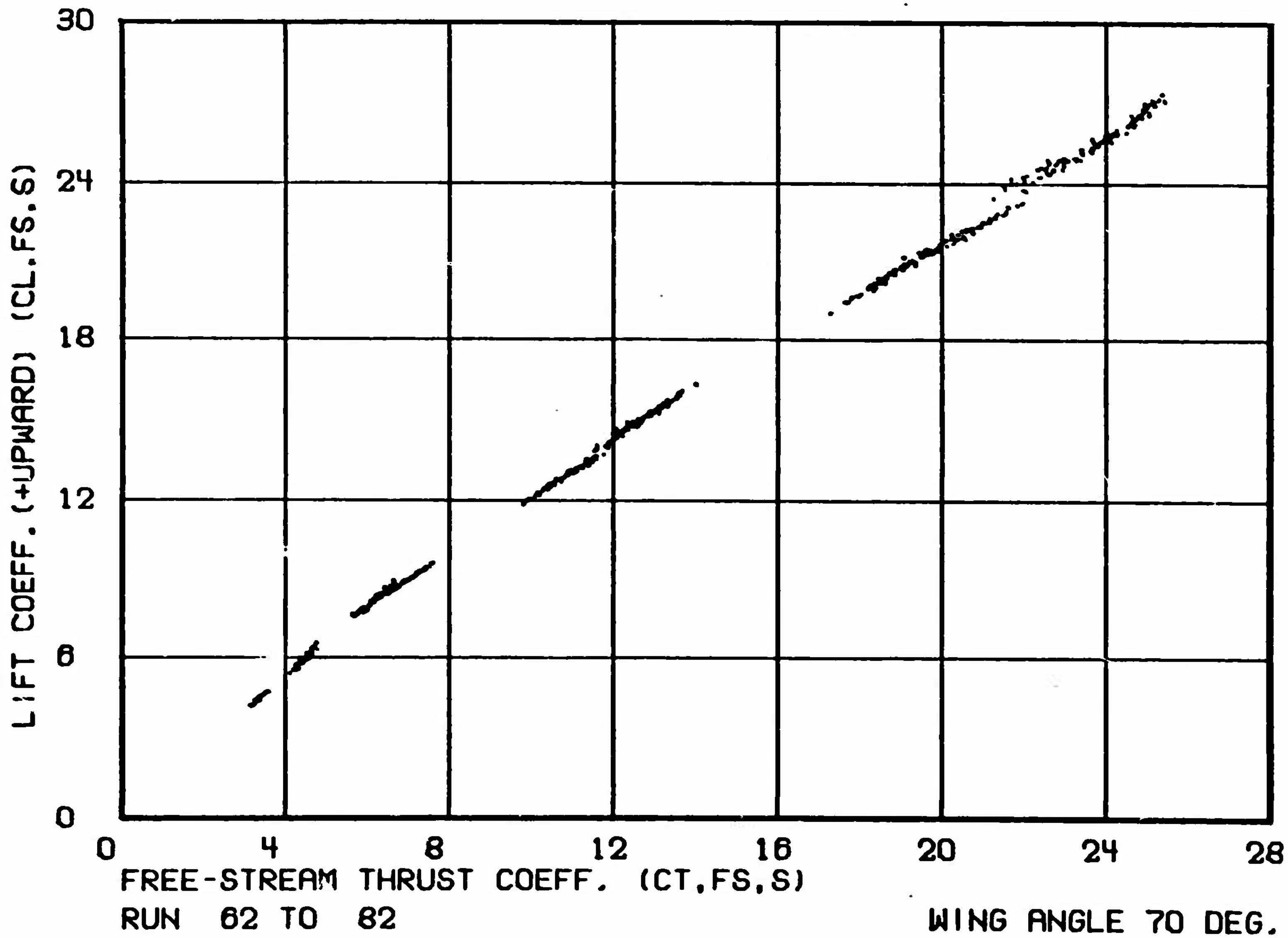

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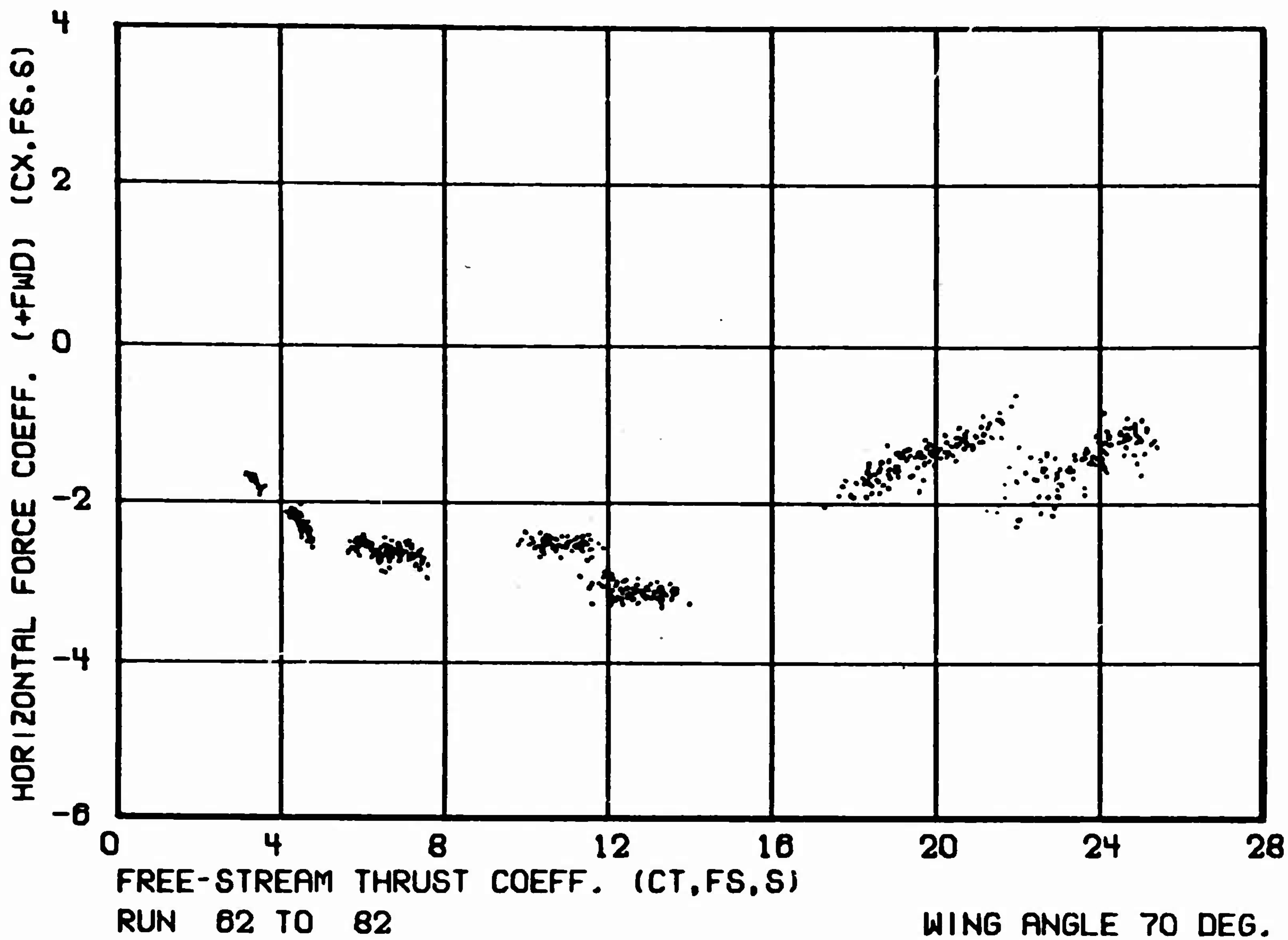

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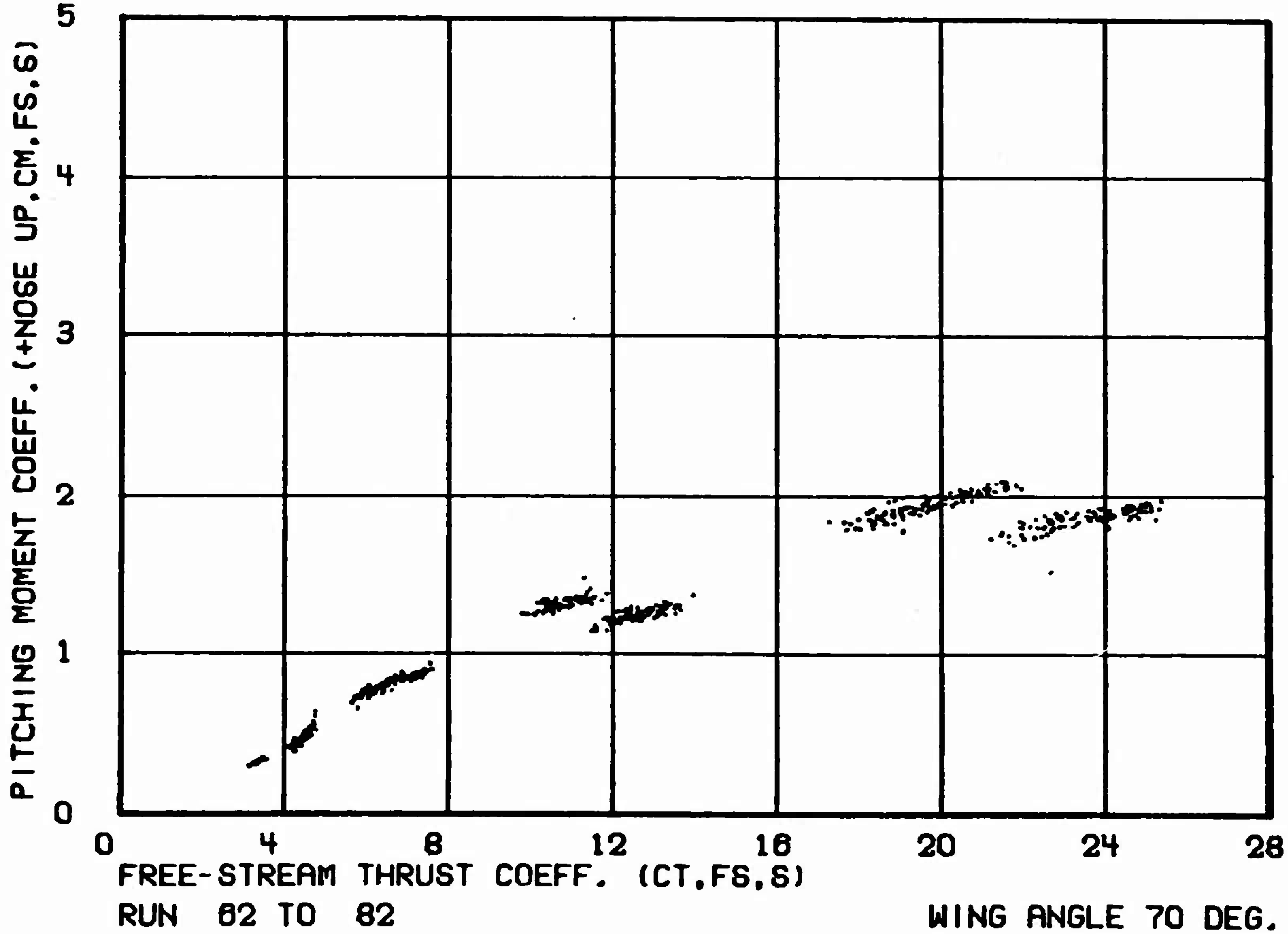

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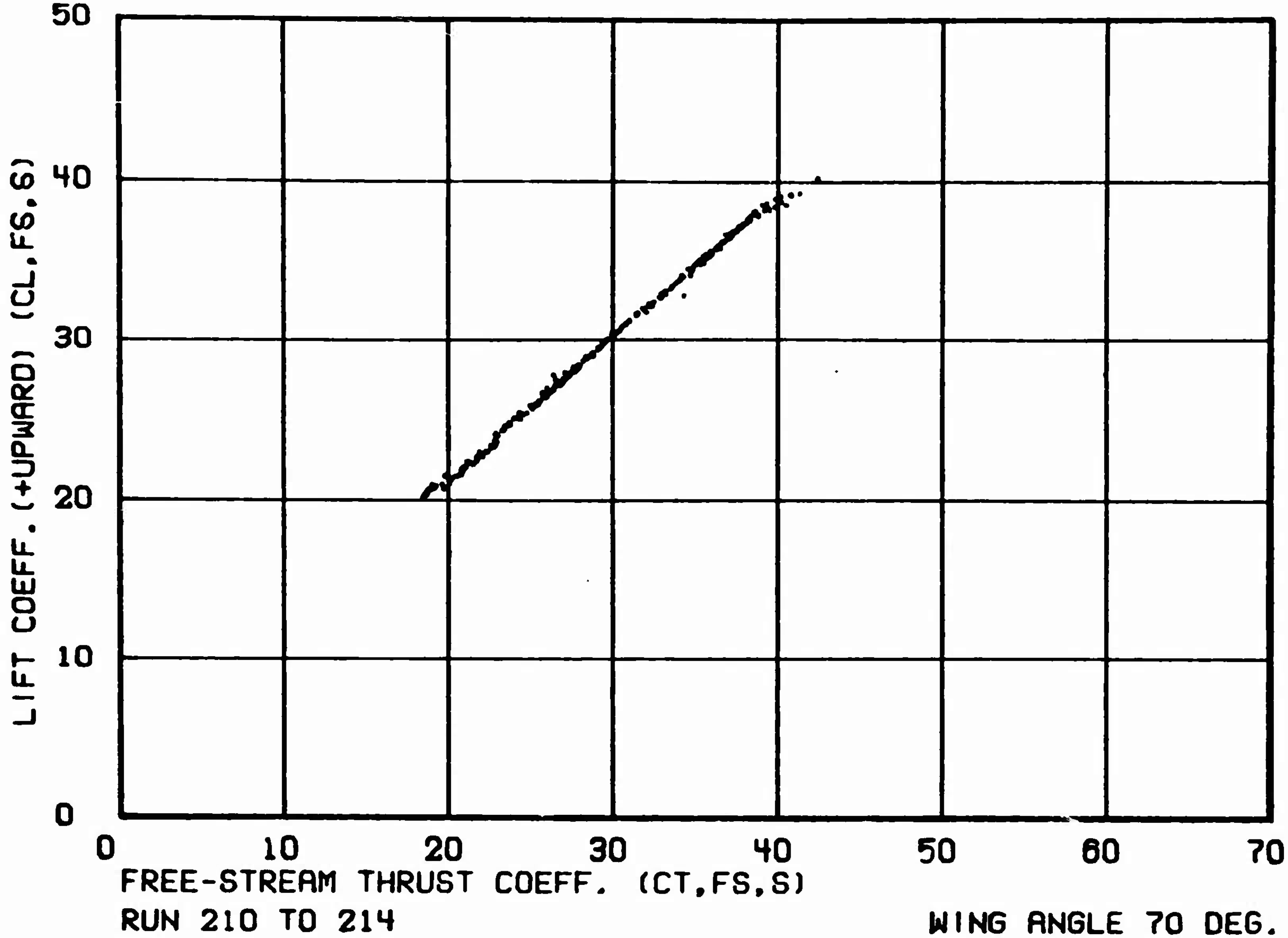

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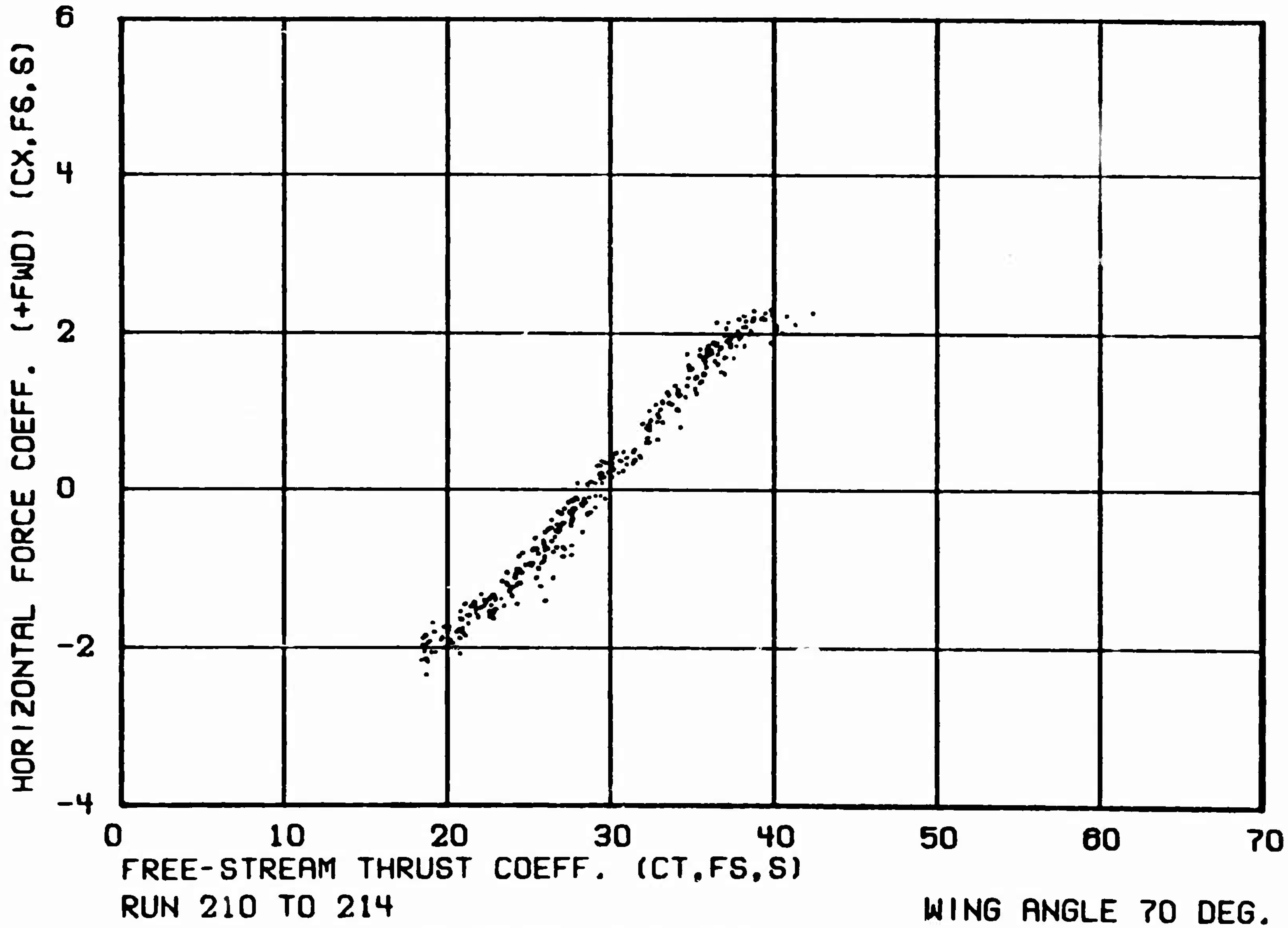

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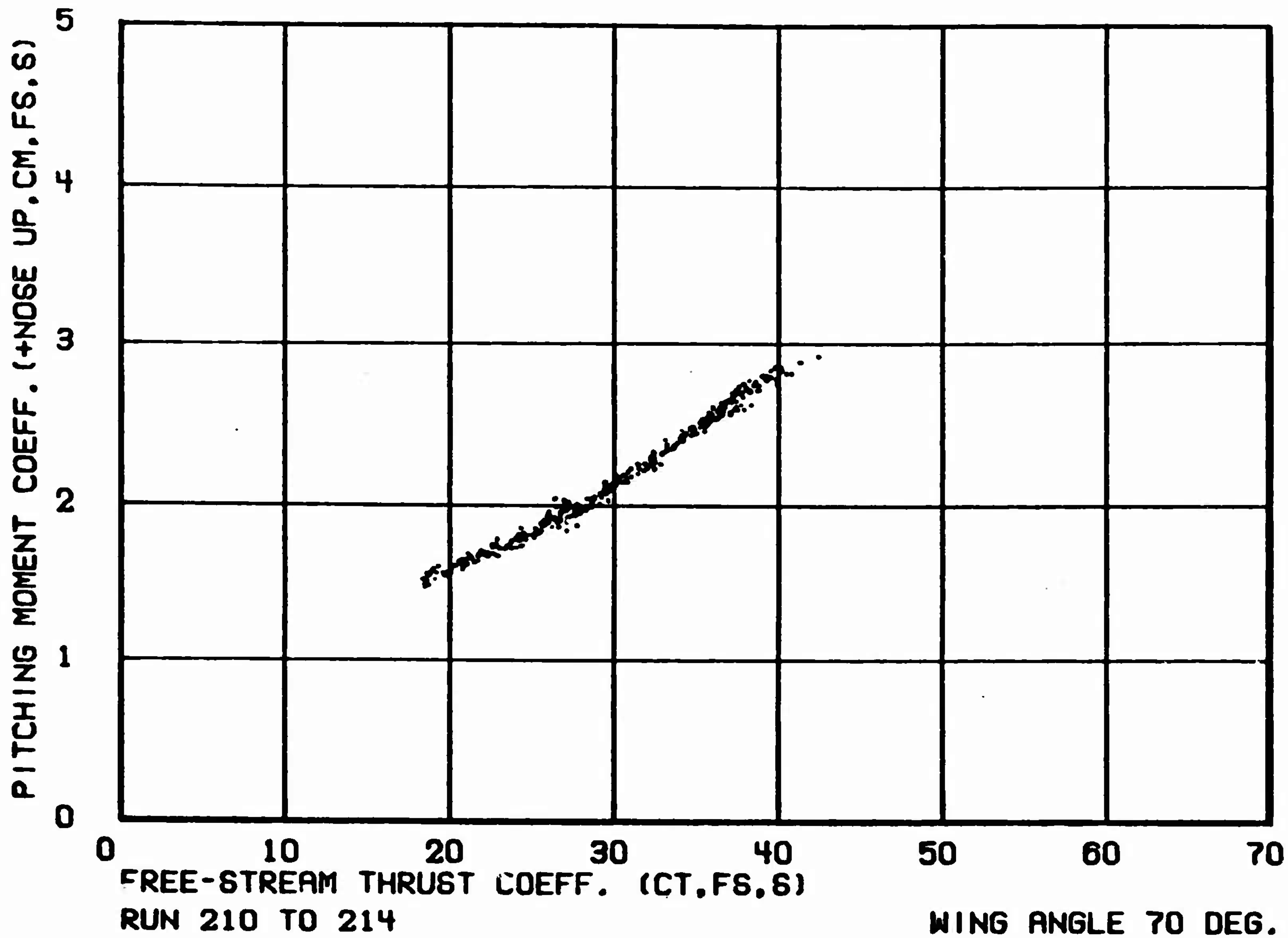

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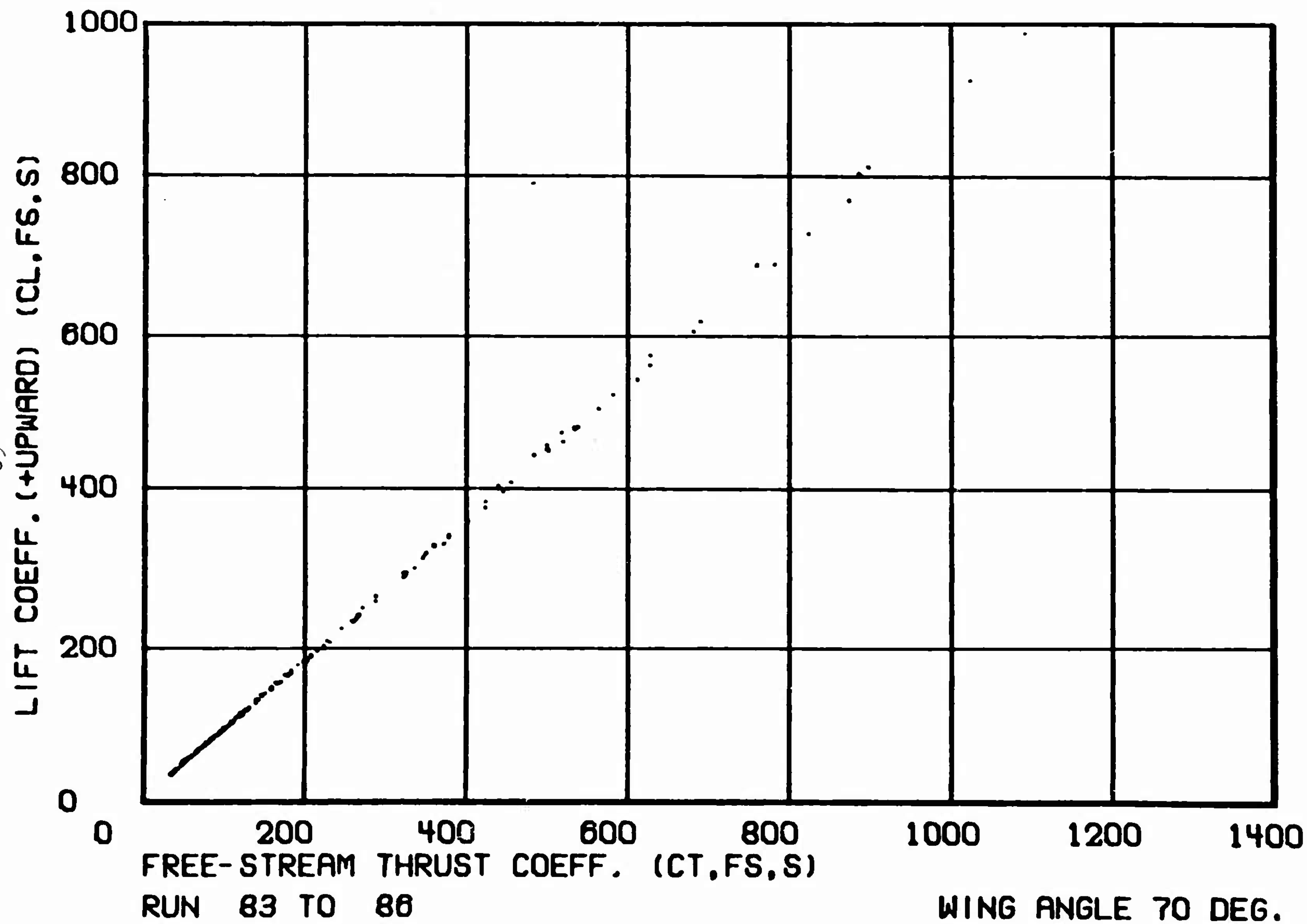

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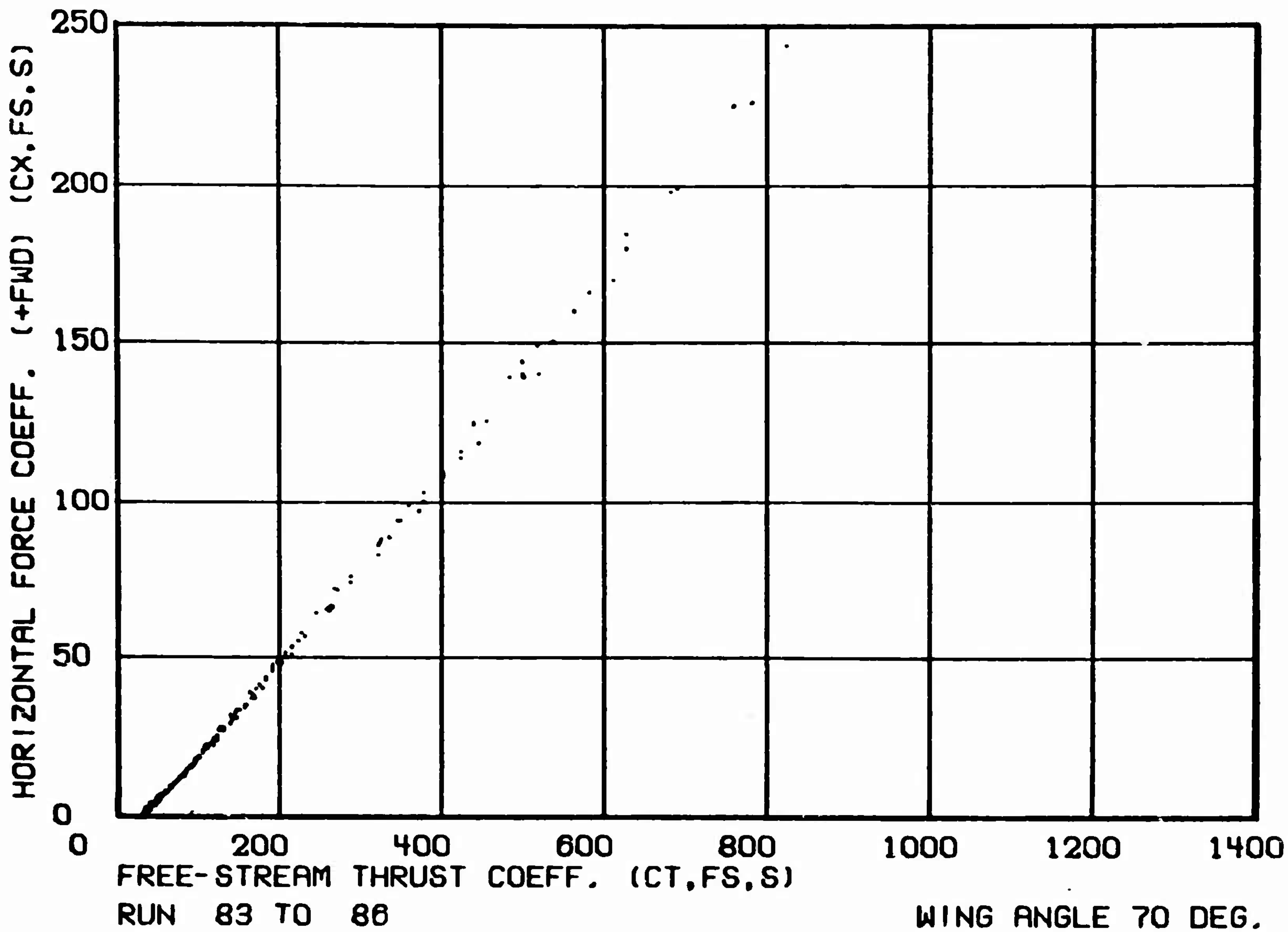

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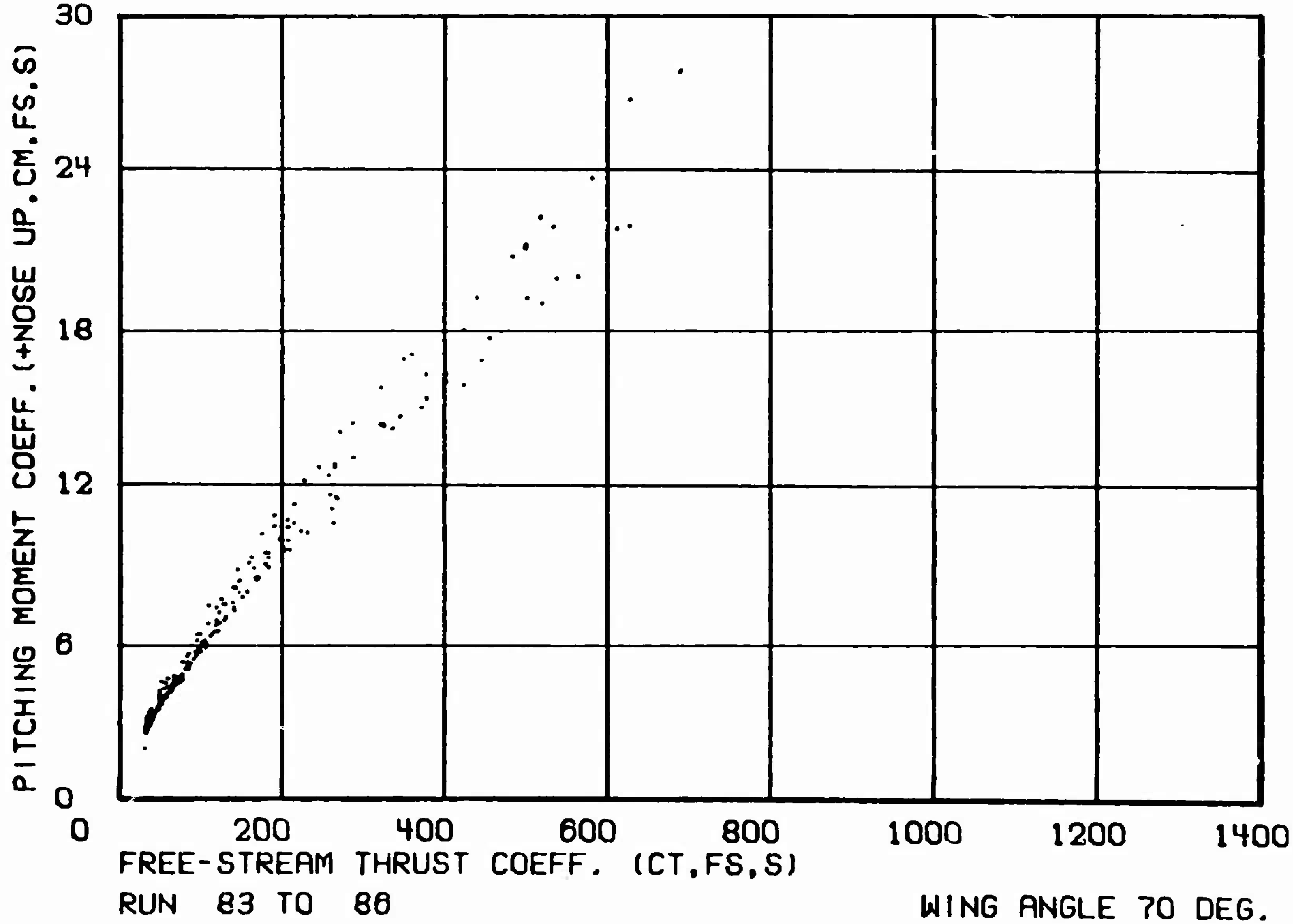

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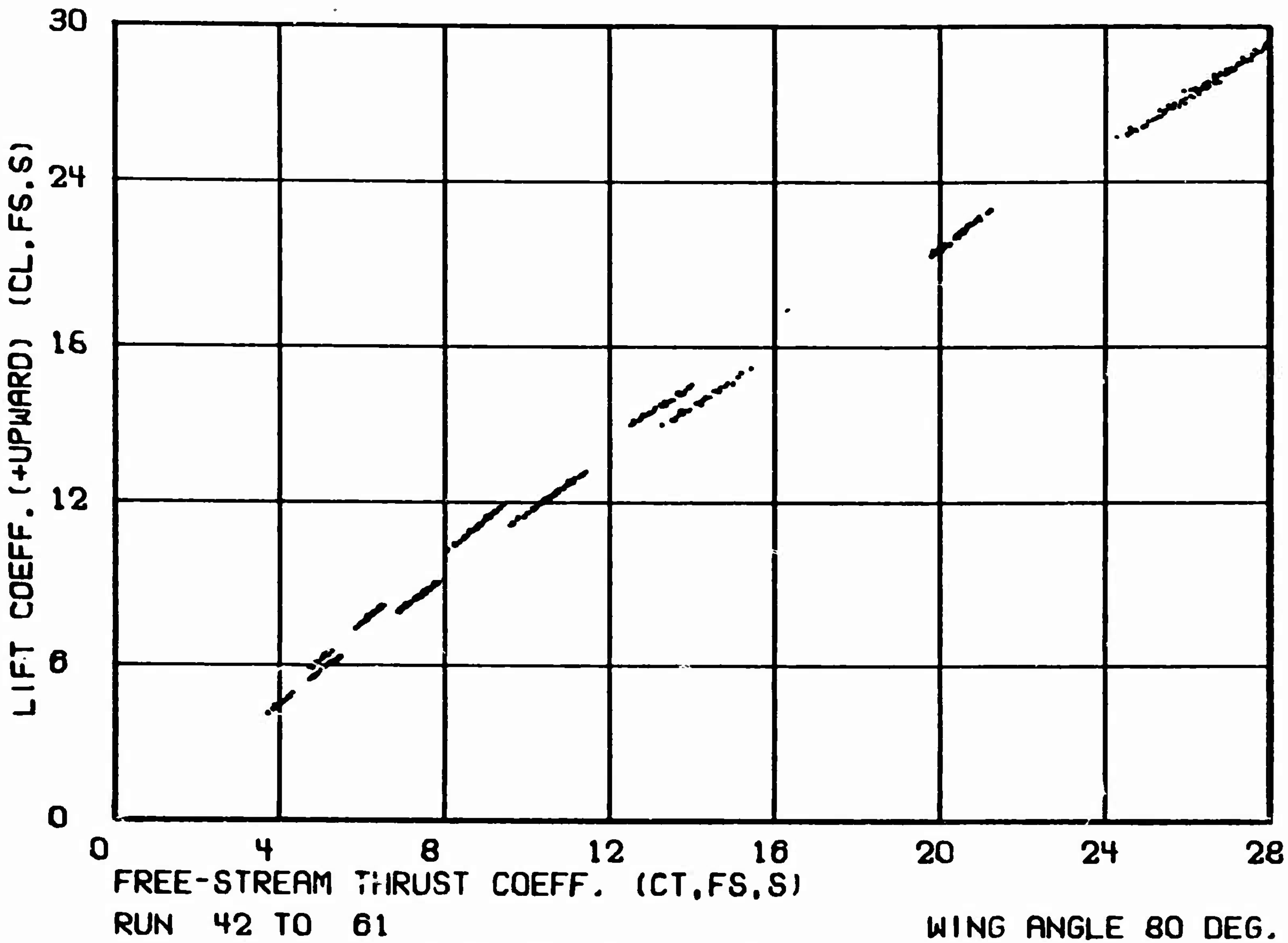

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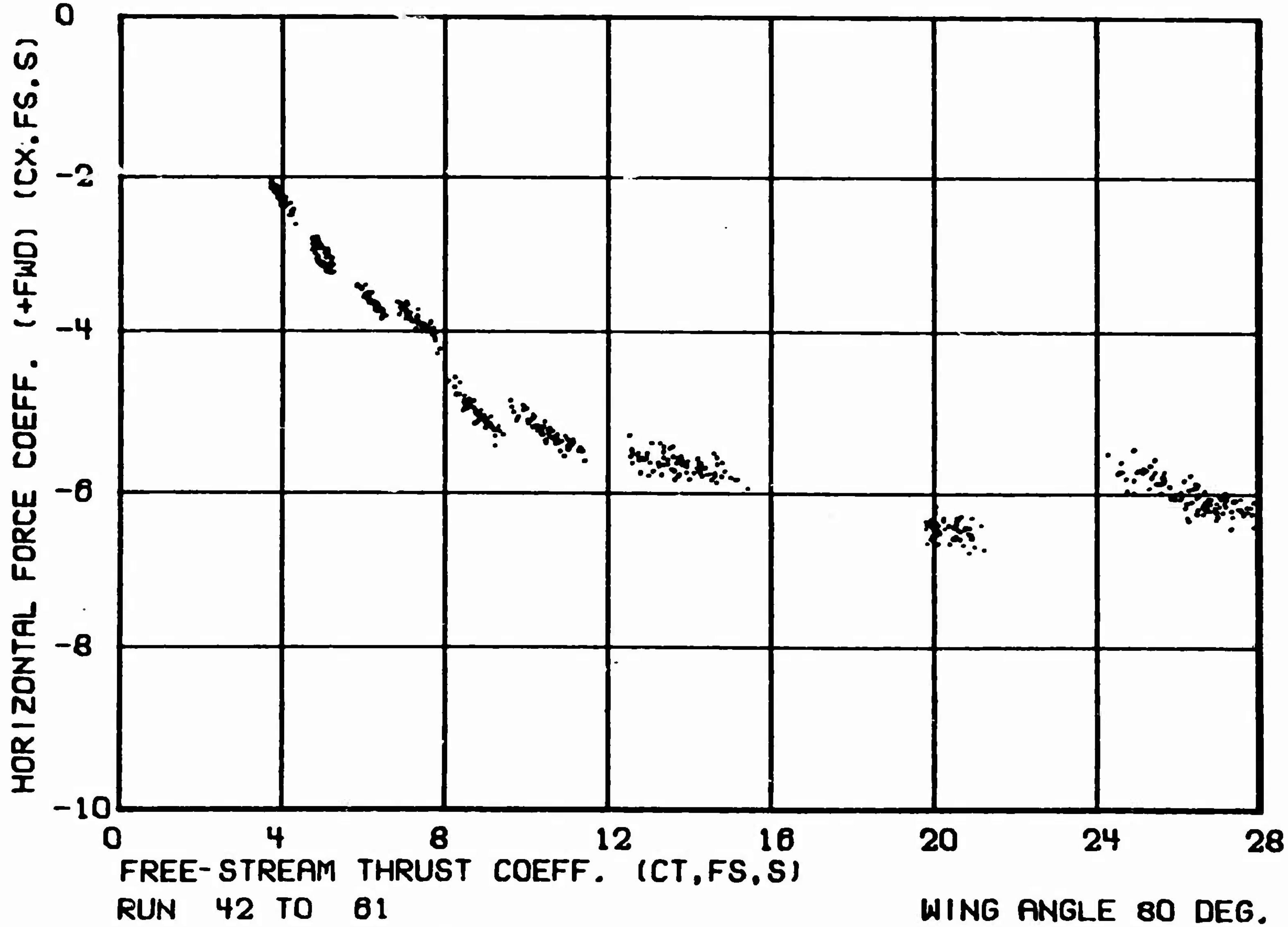

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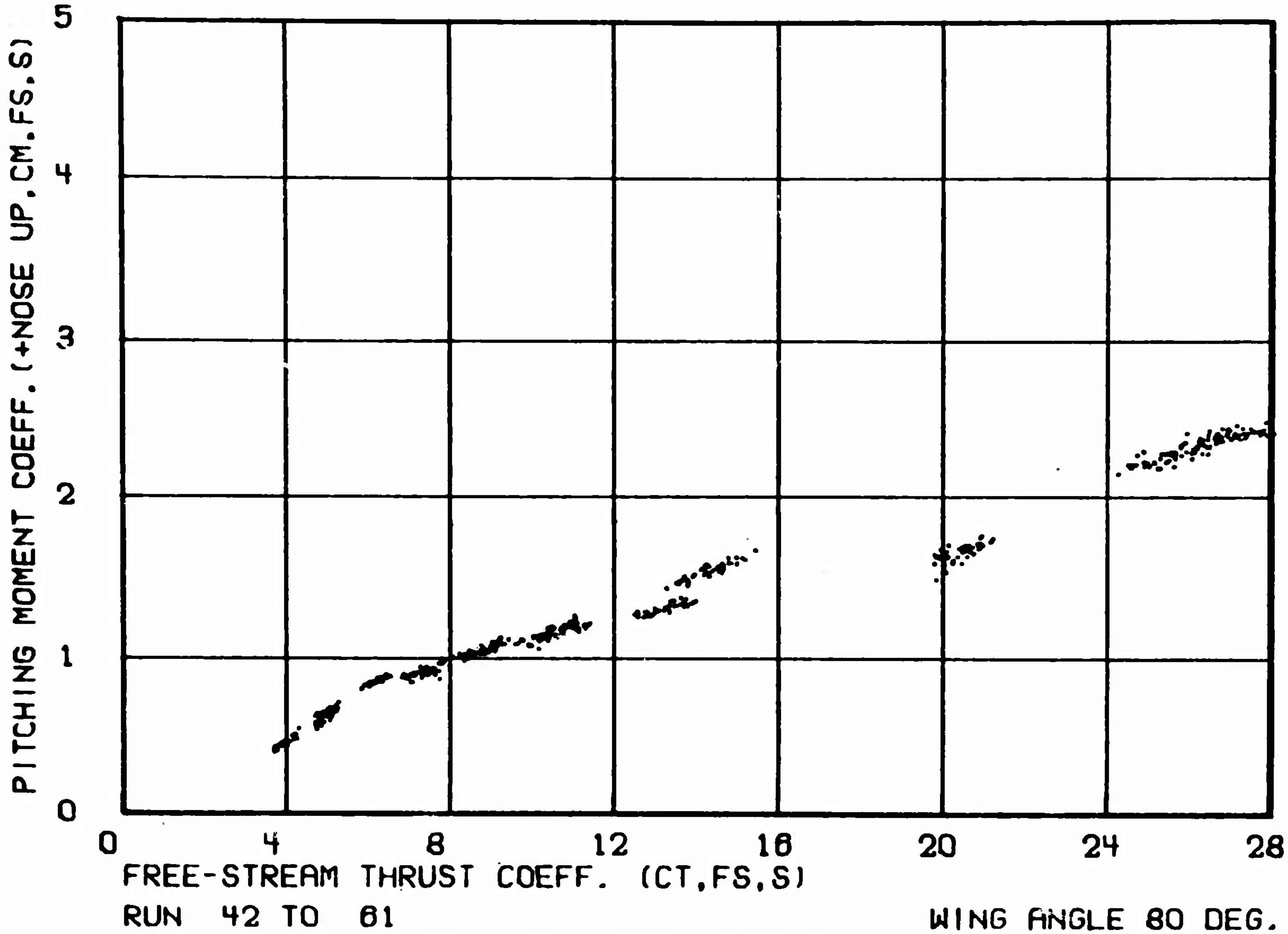

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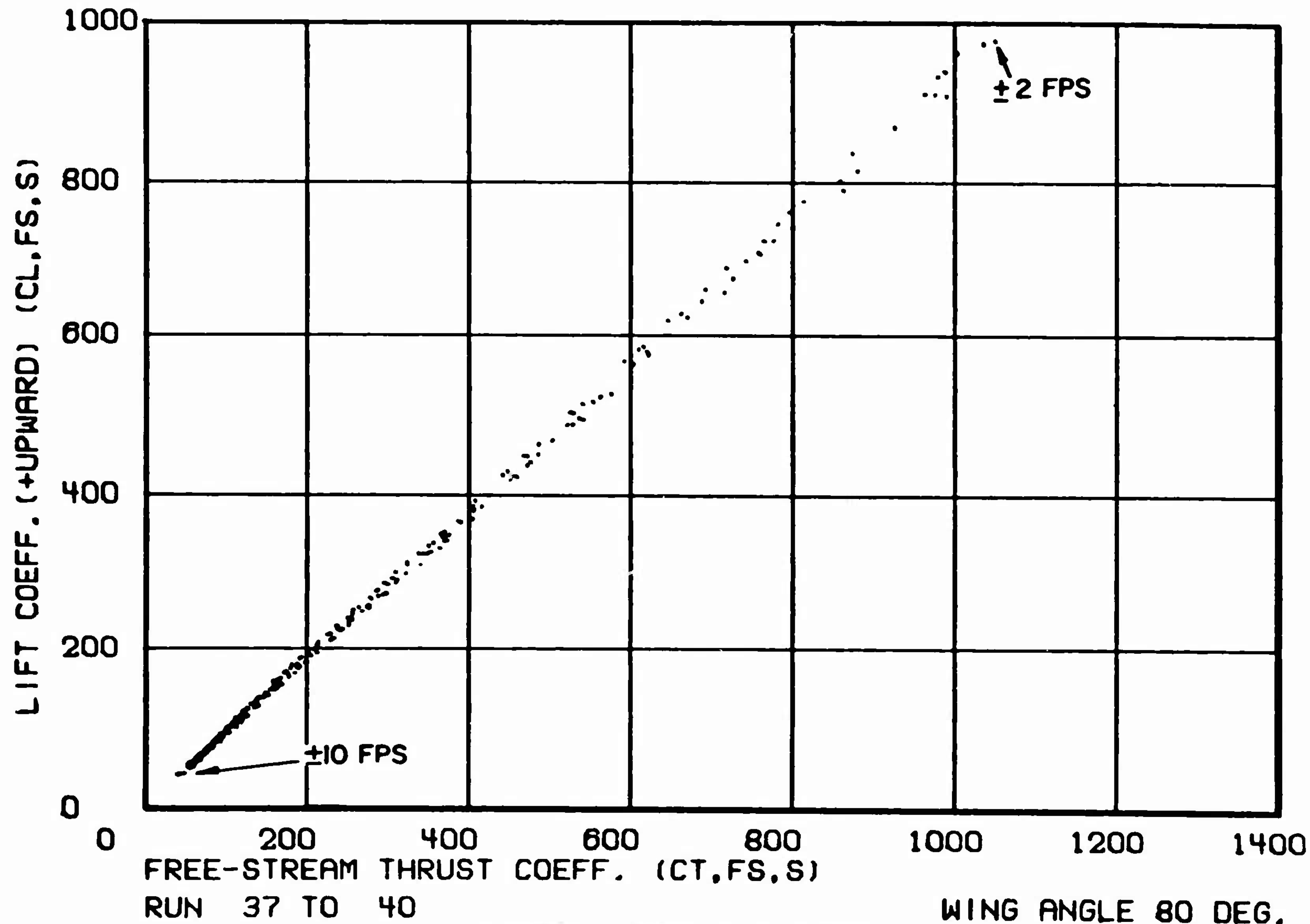

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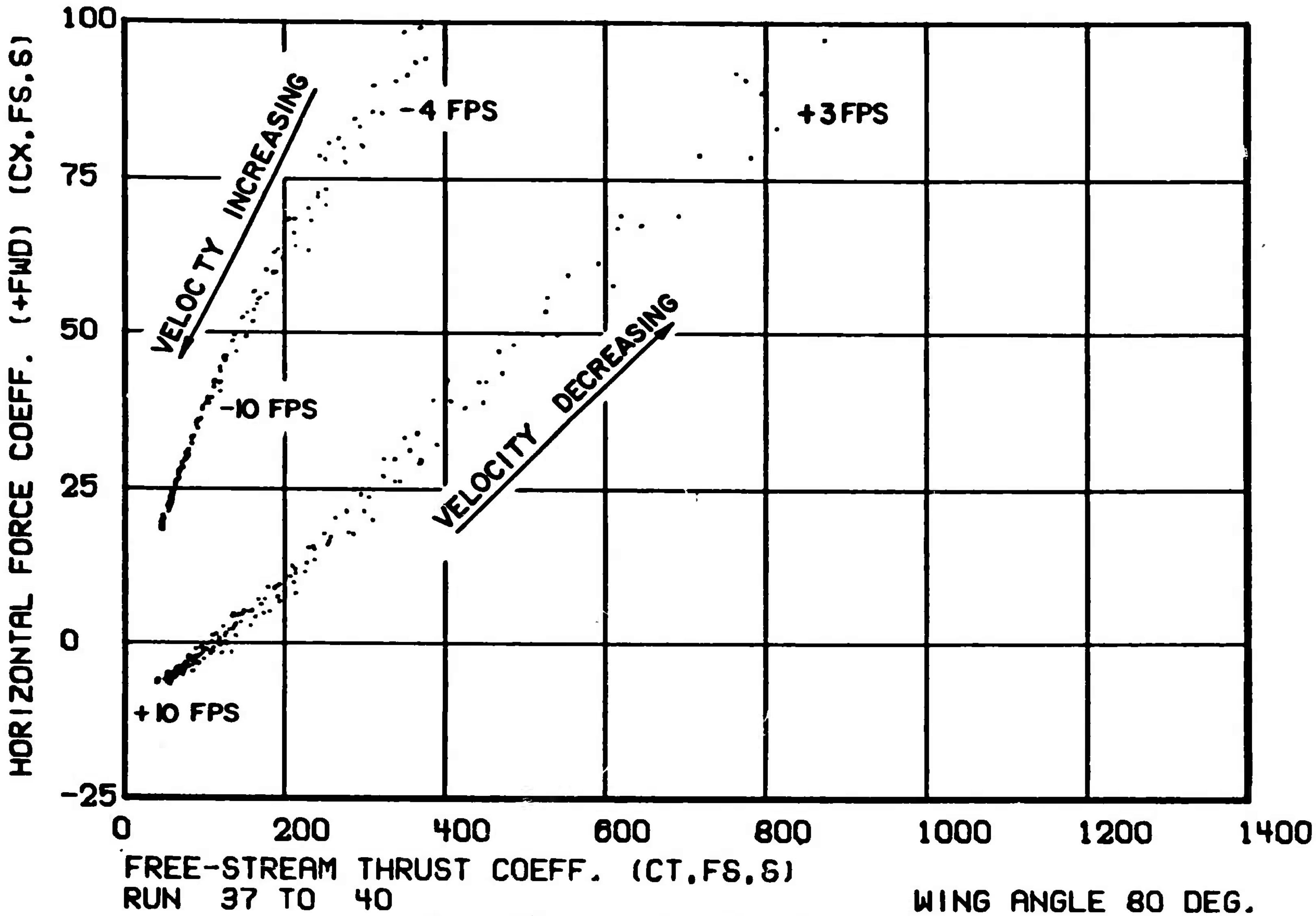

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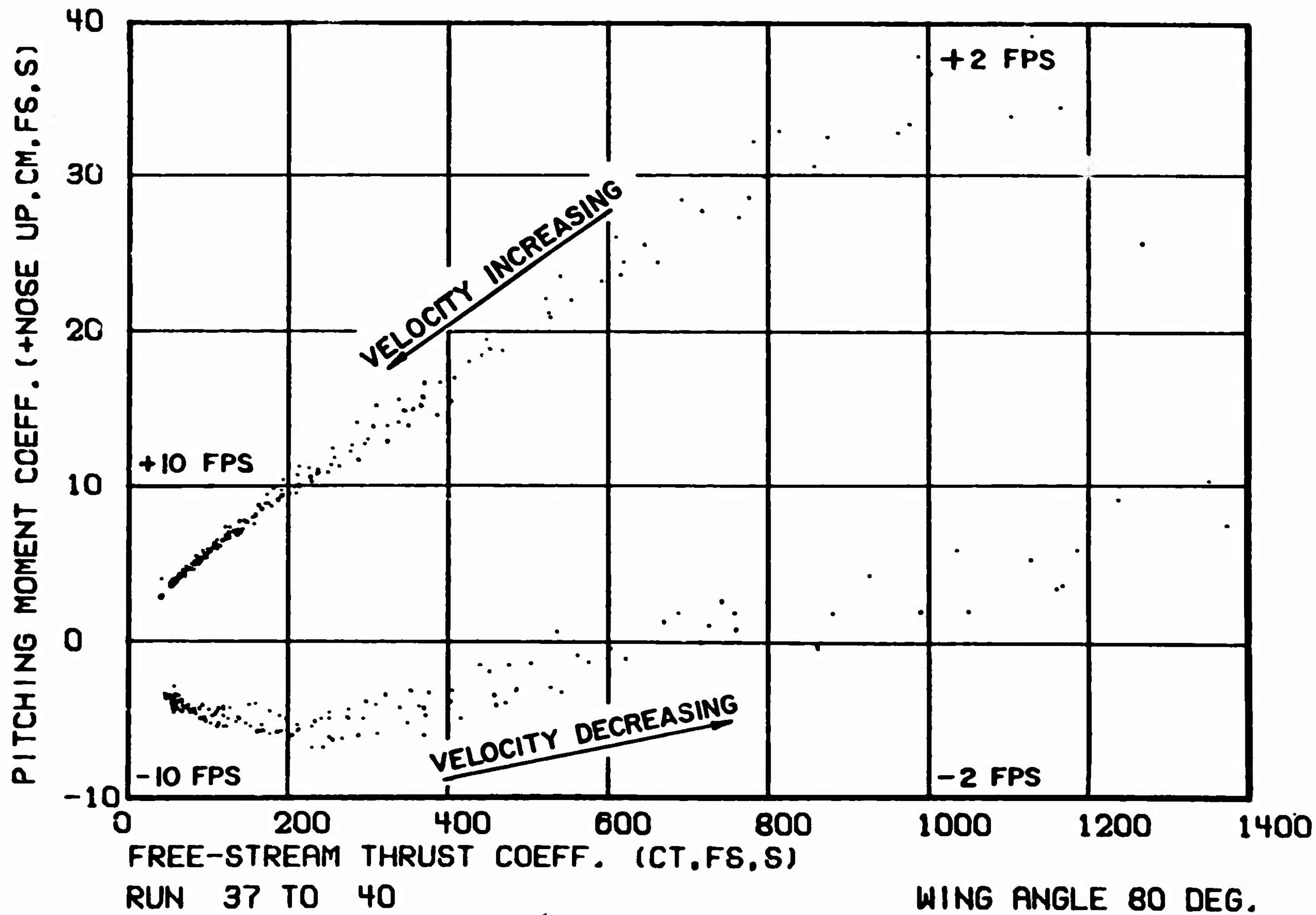

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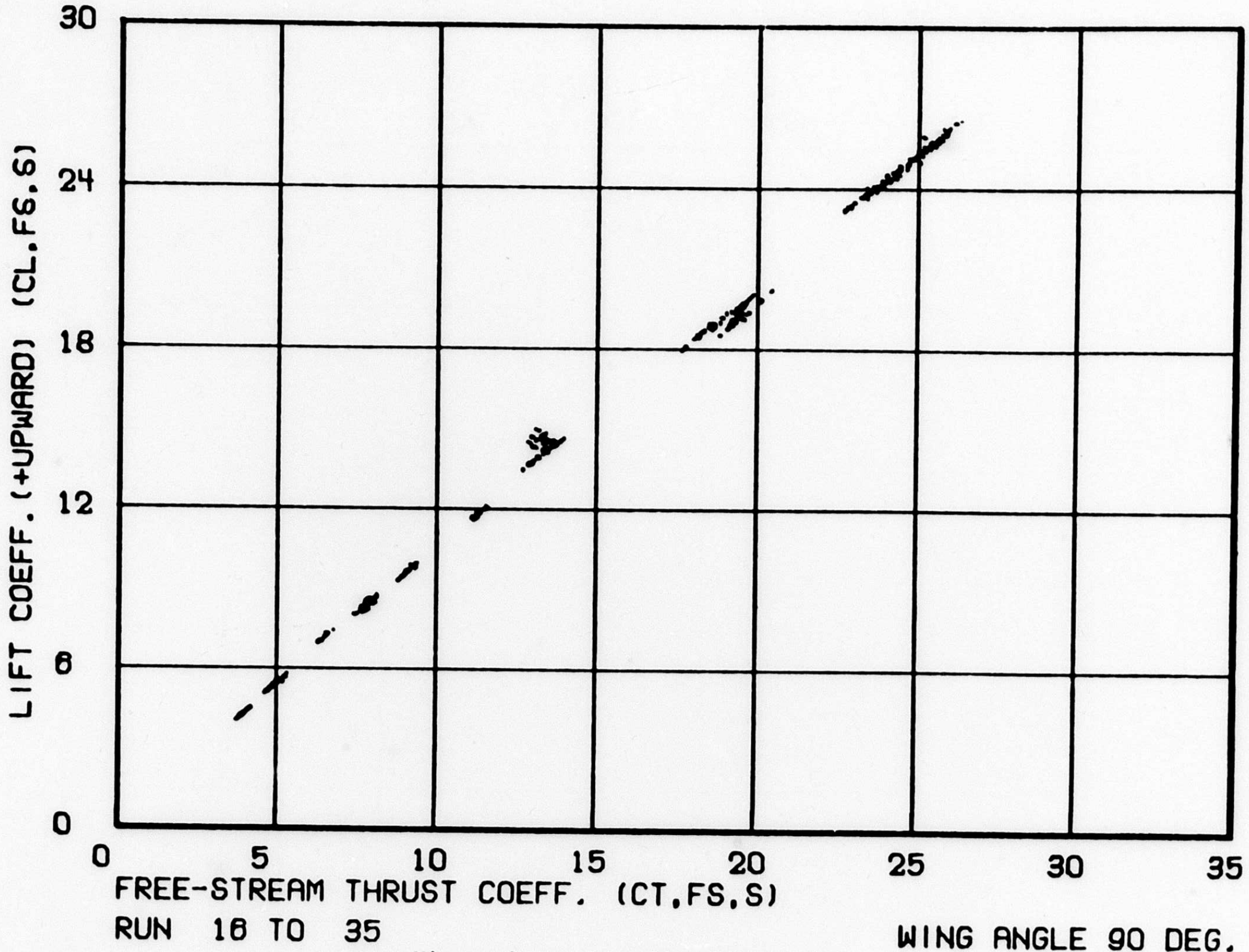

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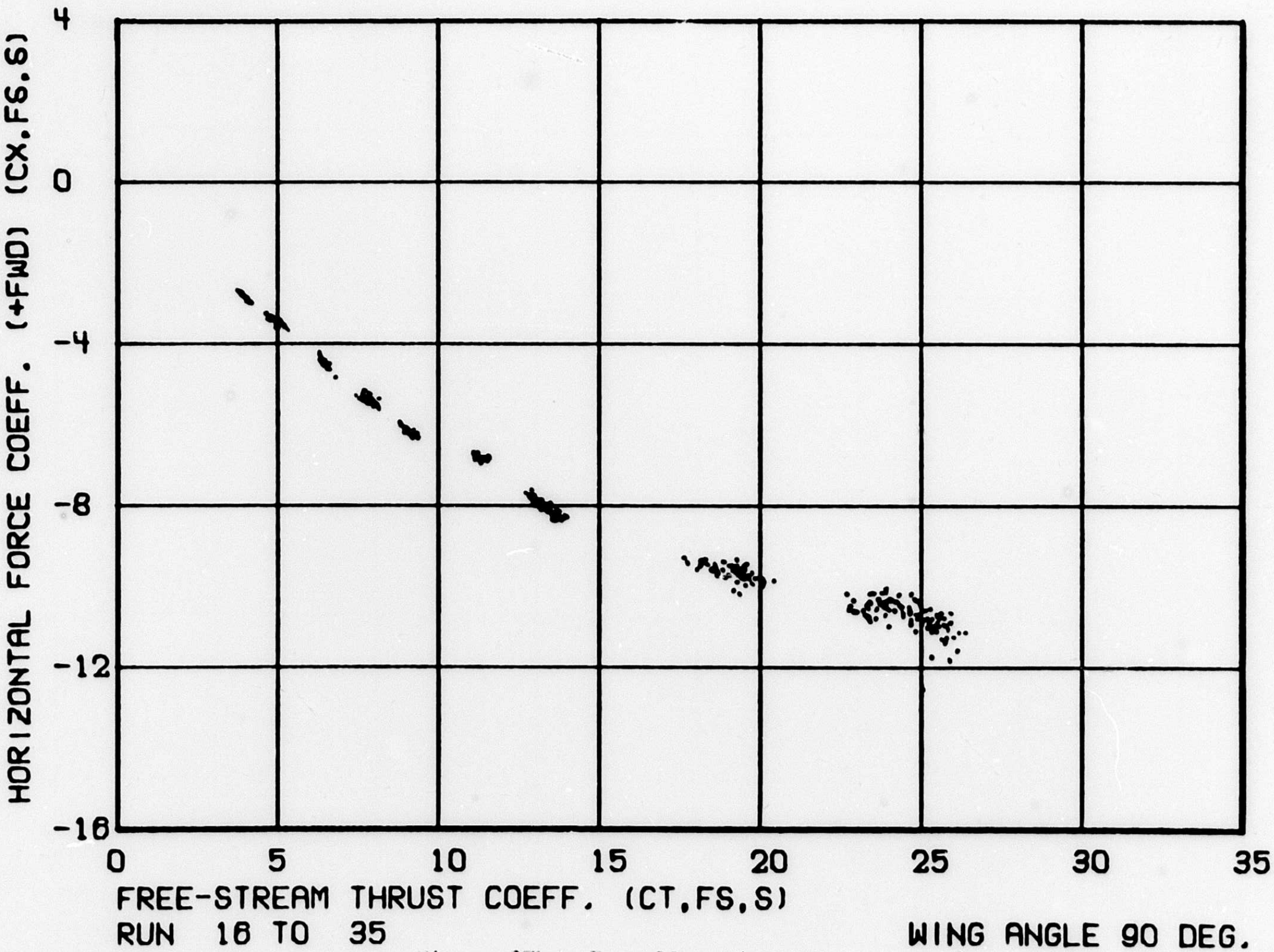

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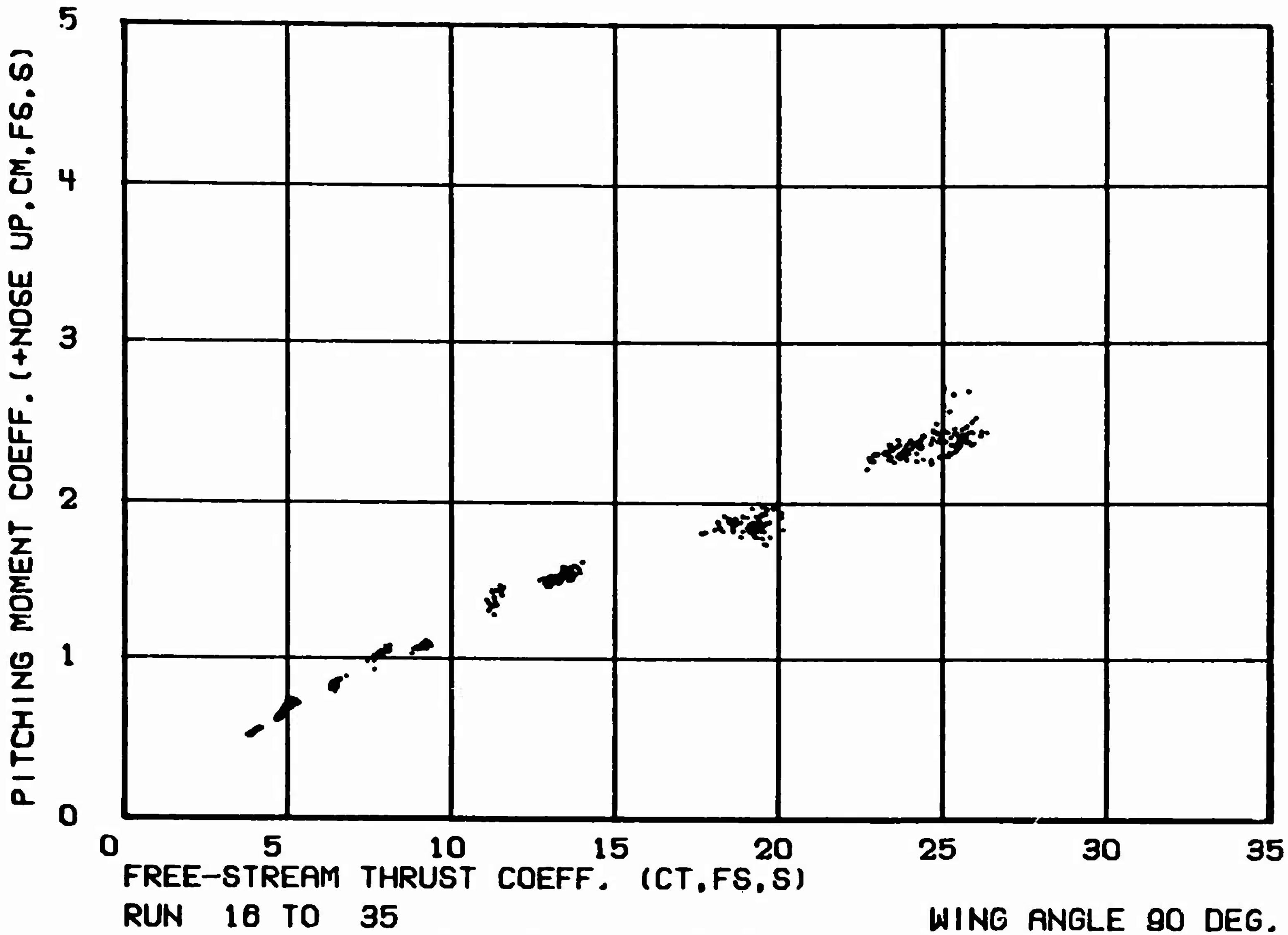

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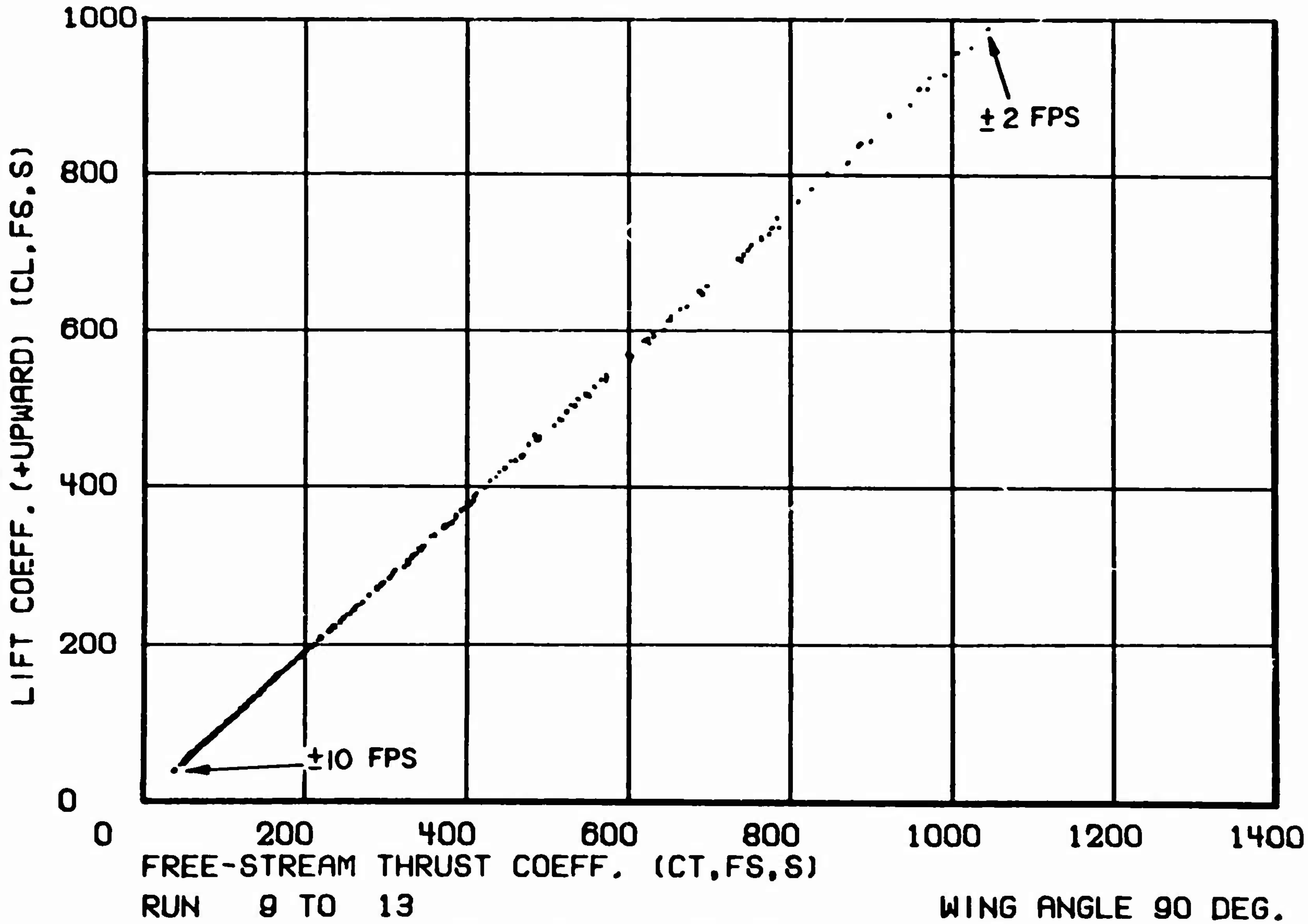

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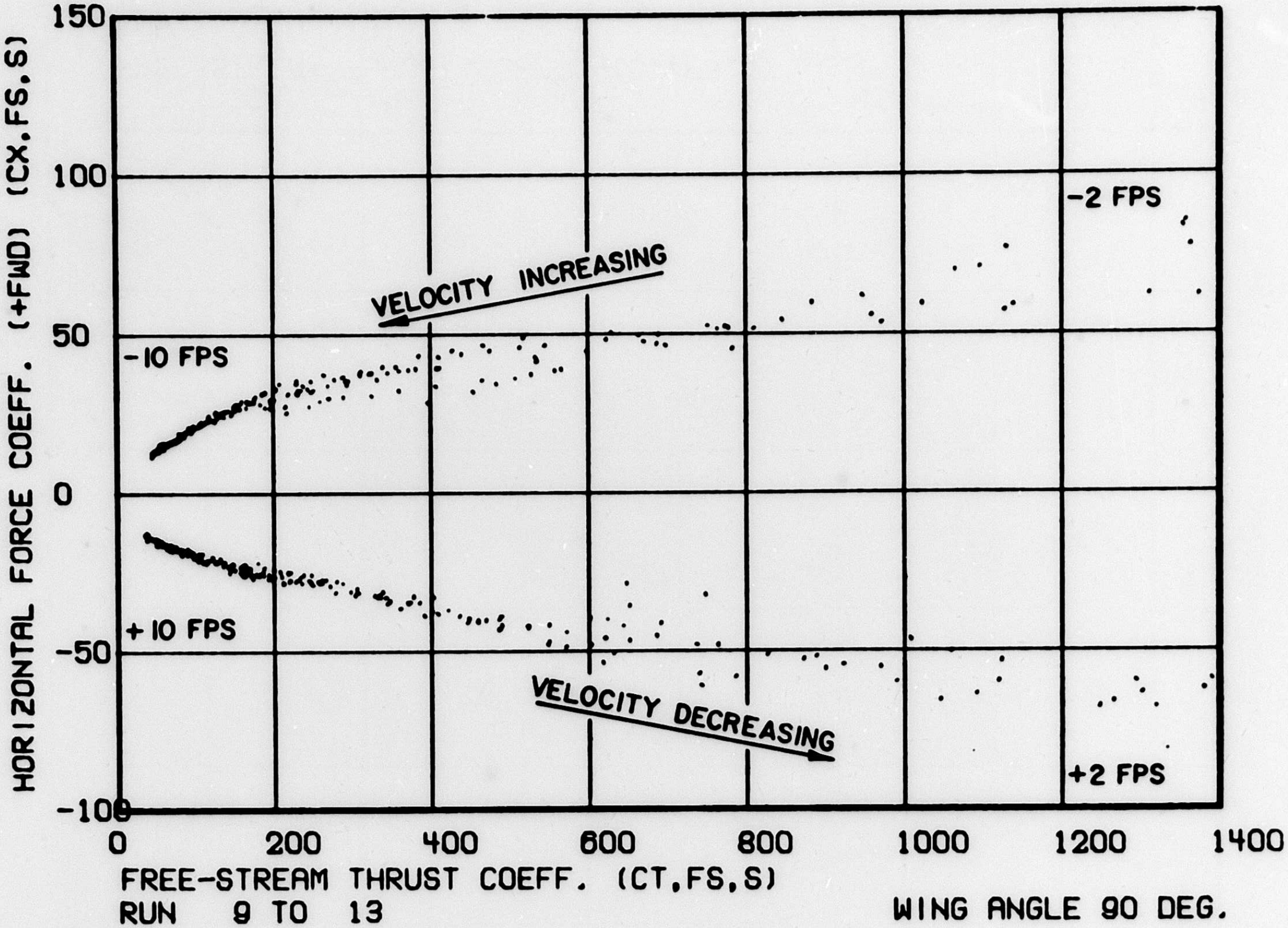

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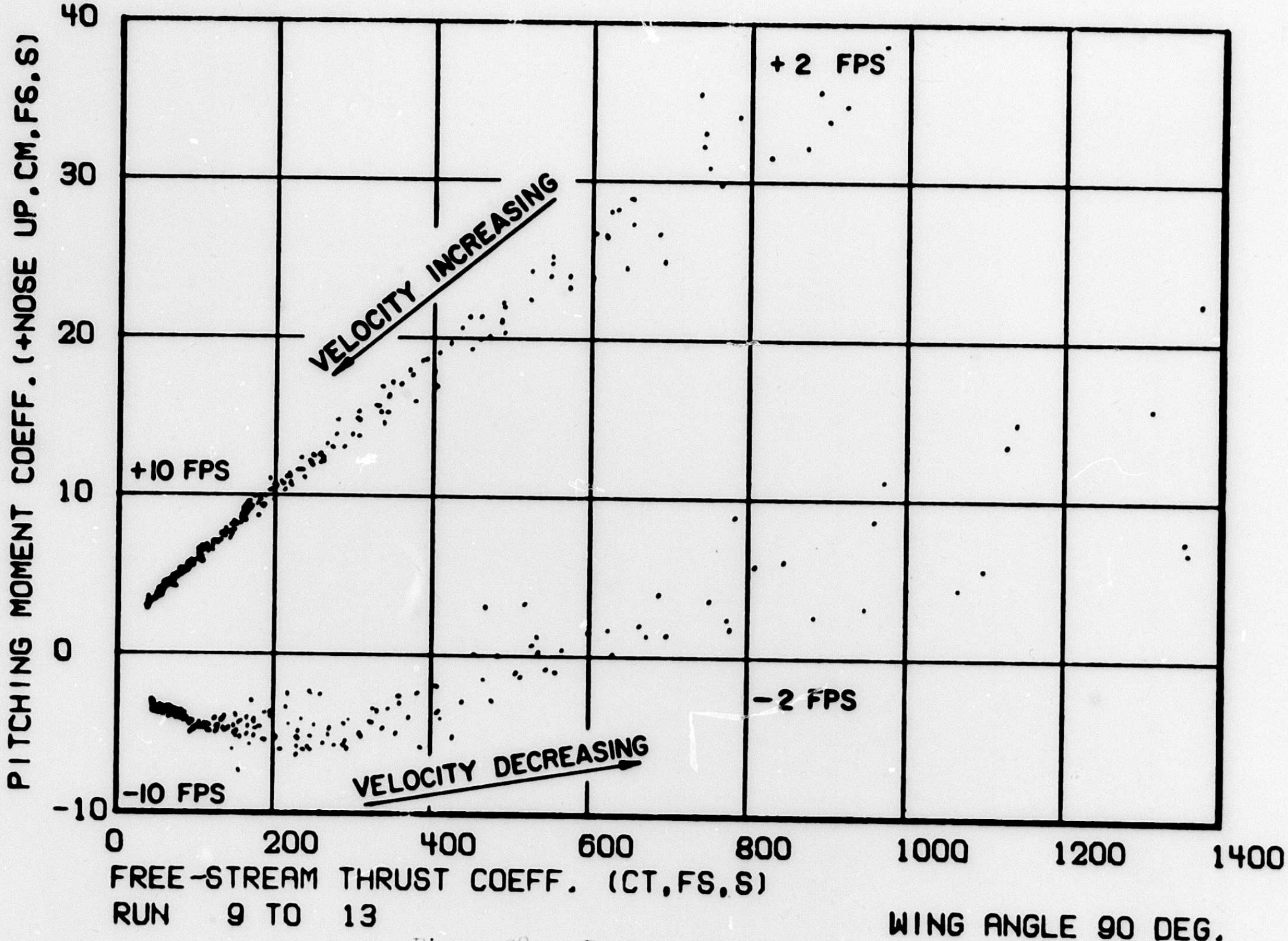

Figure 28c. Propeller-Wing Data

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13. ABSTRACT

The aerodynamic characteristics of a general tilt-wing/propeller model were investigated at the Princeton Dynamic Model Track Facility. The experiments included test conditions corresponding to free-stream velocities from slow backward flight through hovering and transition. Wing incidence angles ranging from 30 degrees (forward flight) to 90 degrees (hovering flight) were investigated. The experimental data are presented in graphs of lift, horizontal force, and pitching moment versus thrust in coefficient form based on free-stream velocity.

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