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MCDONNELL DOUGLAS TECHNICAL SERVICES CO.
HOUSTON ASTRONUTICS DIVISION

SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

DESIGN NOTE NO. 1.4-4-6

ANALYTIC DRAG CONTROLLER GUIDANCE GAINS EVALUATION

MISSION PLANNING, MISSION ANALYSIS AND SOFTWARE FORMULATION

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(NASA-CR-147813) ANALYTIC DRAG CONTROLLER GUIDANCE GAINS EVALUATION. MISSION PLANNING, MISSION ANALYSIS AND SOFTWARE FORMULATION Space Shuttle Engineering and Operations Support (McDonnell-Douglas

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1.0 SUMMARY

This document presents the results of a study to optimize the guidance gains for the Analytic Drag Control (ADC) entry guidance system. The guidance gains were optimized for study points chosen in all phases of entry.

2.0 INTRODUCTION

Lateral logic and roll command are two service routines provided by the entry guidance system. The lateral logic defines a lateral deadband defined about the spacecraft heading. If the magnitude of the difference between the spacecraft heading and the heading to the target exceeds the limits defined by the deadband and the roll direction is such that this difference will increase, the guidance will command a roll reversal. The roll reversal, therefore, is used to control cross range capability. The roll command service routine generates a roll command for the entry guidance system and the roll direction is reversed by changing the sign of the roll command generated.

These roll reversals will cause trajectory deviations. There will be a change in the actual drag-velocity profile as a result of the reversal. During the roll reversal there will be a decrease in the drag acceleration level and following the reversal there will be an increase in the drag acceleration thus causing a phugoid motion about the reference drag profile.

The purpose of this study is to optimize the guidance gains in order to minimize these trajectory deviations. The criteria used in minimizing the deviations are obtaining satisfactory recovery of the actual drag acceleration to the reference drag acceleration profile and minimization of the magnitude of the roll command during the roll reversal.

3.0 DISCUSSION

Six study points were chosen in all phases of entry along a typical entry trajectory (Figures 1-2). Figure 1 presents the study points in an altitude-velocity plane and Figure 2 presents the study points in a drag-time from the entry interface plane.

For this study a constant angle-of-attack profile of 35.75° was used during entry with a linear ramp of angle-of-attack at a relative velocity of 13,600 feet per second down to 10° at TAEM interface.

In each guidance cycle of an entry trajectory an analytic reference trajectory is computed. The controller receives a reference lift-to-drag ratio, (L/D_{ref}), reference drag level, ($DRAG_{ref}$), and altitude-rate reference, ($HDOT_{ref}$). An inplane lift-to-drag ratio (L/D_V) is computed in the following equation:

$$L/D_V = L/D_{ref} + C16\ (DRAG-DRAG_{ref}) - C17\ (HDOT-HDOT_{ref}) \tag{3-1}$$

where C16 and C17 are the guidance gains, DRAG the actual drag acceleration level, and HDOT the altitude-rate.

In each guidance cycle a difference (DELAZ) between the spacecraft heading and heading to target is calculated. If the magnitude of

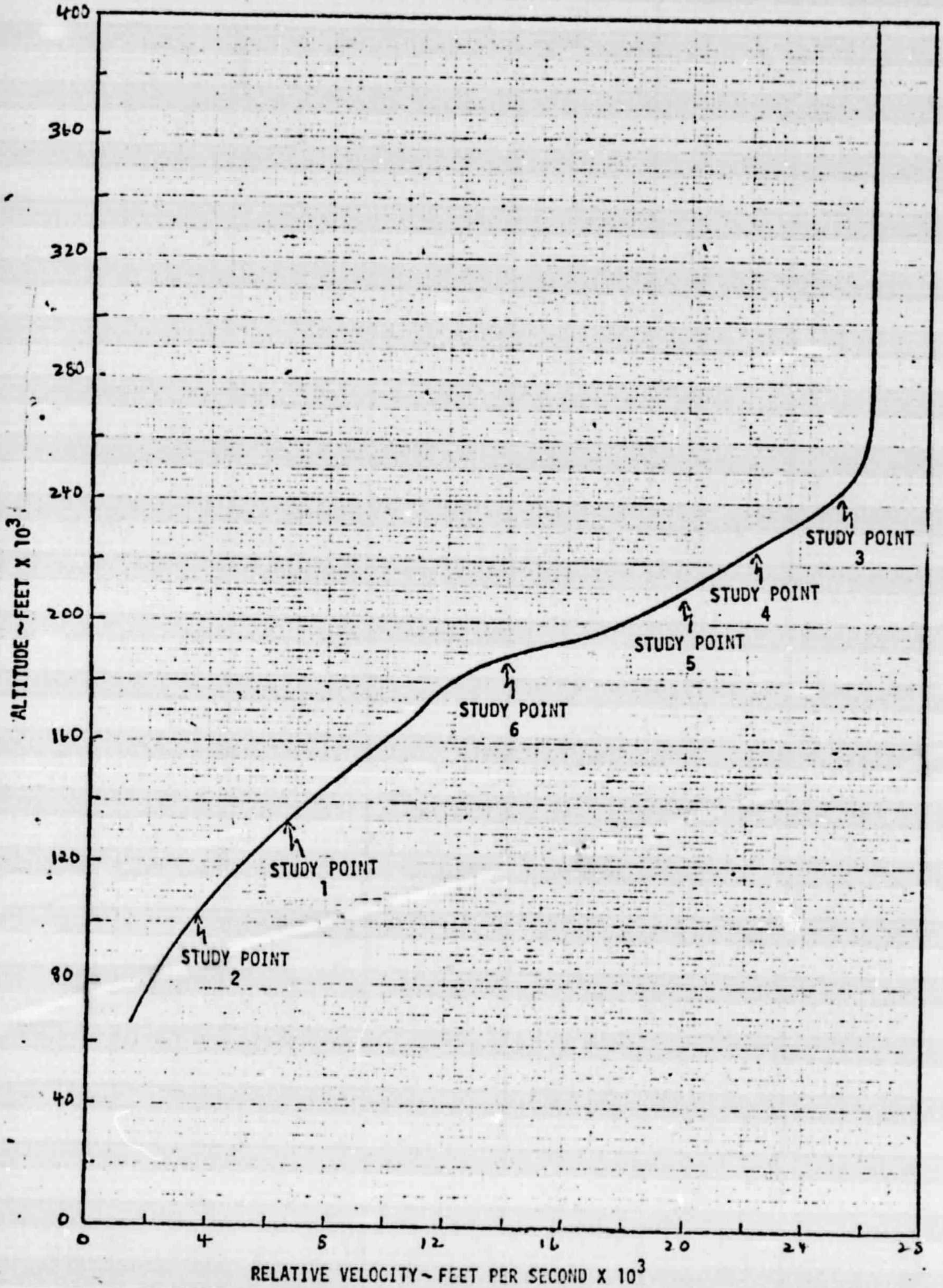

FIGURE 1. - STUDY POINTS IN THE ALTITUDE-VELOCITY PLANE.

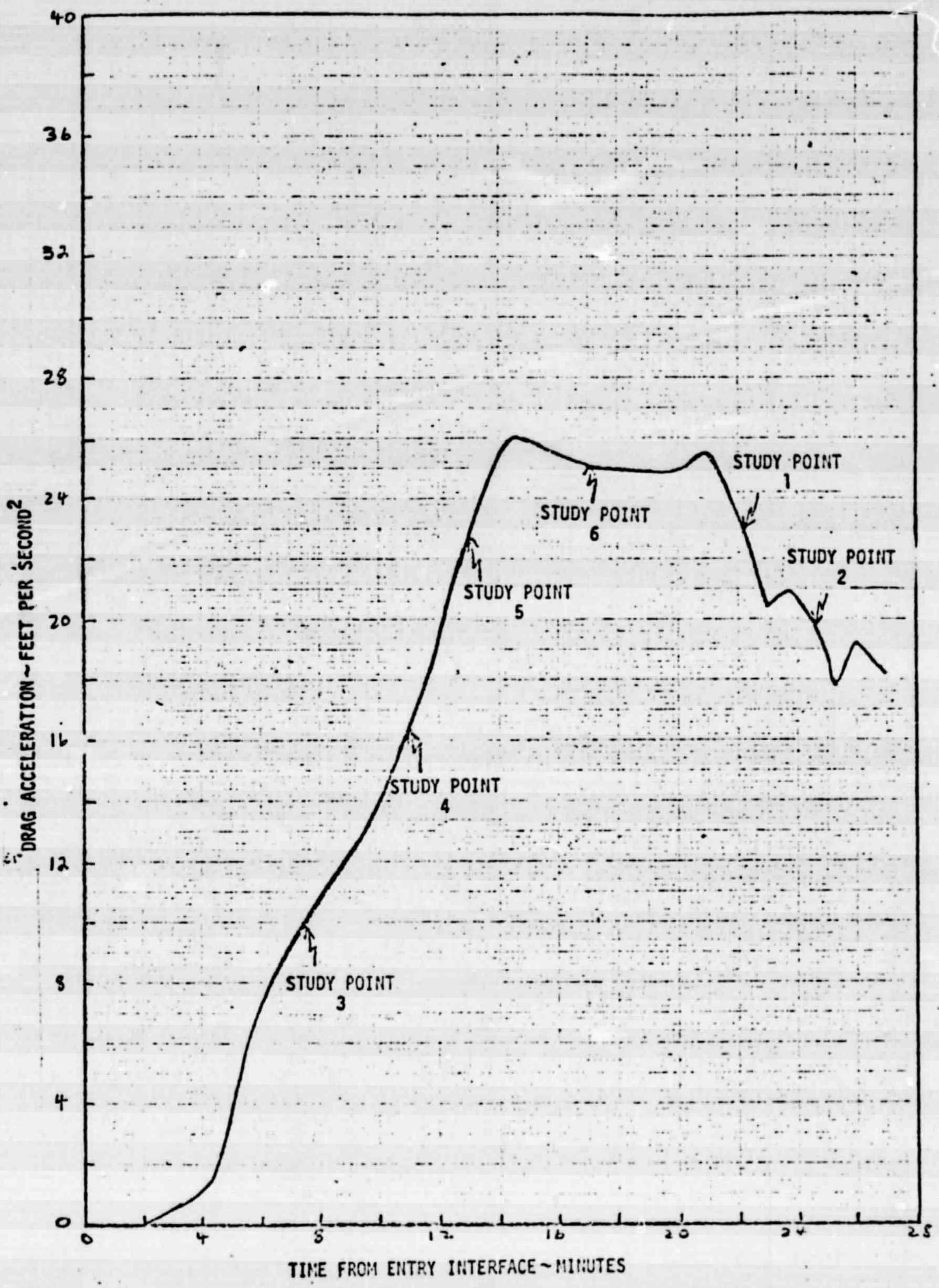

FIGURE 2. - STUDY POINTS IN THE DRAG-TIME FROM ENTRY INTERFACE PLANE.

this difference exceeds the lateral deadband defined about the heading and the sign of the roll command (RK2ROL) times DELAZ is positive, the sign is changed. The roll command (ROLLC) generated in each guidance cycle to follow the guidance computed reference drag-velocity profile is computed by the following equation:

$$ROLLC = RK2ROL \times COS^{-1}\left(\frac{L/D_V}{L/D}\right) \qquad (3\text{-}2)$$

where L/D_V is the inplane lift-to-drag ratio command, L/D the total lift-to-drag ratio and RK2ROL is $\pm$ 1. Therefore, a change in sign of RK2ROL initiates a guidance commanded roll reversal to ensure cross range capability.

The guidance gains, C16 and C17, in equation 3-1 have an effect on the trajectory response to a roll reversal and this study optimizes these guidance gains. The current values of the gains are functions of drag acceleration and were used as initial values in the optimization. The method used to determine the optimum C16 and C17 was to initialize the trajectory at a study point and command a reversal by setting the initial roll angle to the opposite sign. The guidance gains were then optimized by minimizing the drag overshoot, drag undershoot, (figure 3) and roll angle change as a function of C16 and C17 and then select the values of C16 and C17 which best satisfy all three conditions.

The trajectory response to the roll reversal was analyzed using the above criteria. The drag undershoot reflects the decrease in drag acceleration during the roll reversal and is measured by the magnitude

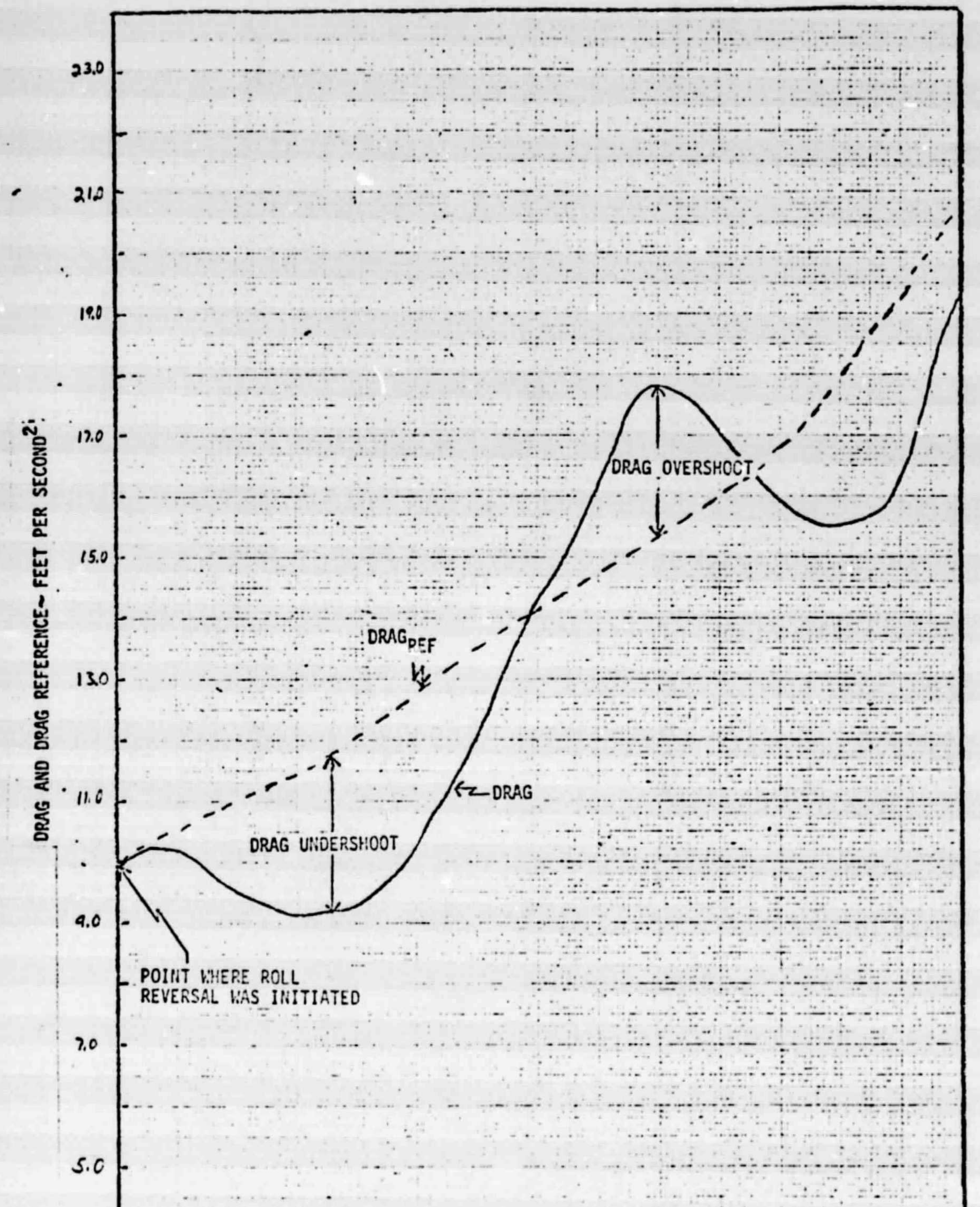

FIGURE 3. - EXAMPLE DRAG RESPONSE TO A ROLL REVERSAL.

of the $DRAG-DRAG_{ref}$ term. The larger this initial deviation the longer the time required to re-establish the desired drag-velocity profile. The drag overshoot reflects the increase in the drag acceleration level following the roll reversal. This increase is caused by the phugoid motion resulting from initial decrease in drag. The drag overshoot is also measured by the magnitude of the $DRAG-DRAG_{ref}$ term.

4.0 RESULTS

The initial conditions for the six study points are given in Table I. Acceptable ranges for C16 and C17 are given in Table II and presented graphically in Figures 4 and 5. The results for each study point are summarized in Figures 6 through 17.

The gains were optimized for a 1.0 deg/sec^2 and .85 deg/sec^2 roll acceleration with a maximum roll rate of 5.0 deg/sec resulting in no difference in gains required for the different acceleration levels.

The gains were optimized with ± 40 ft/sec errors applied to the navigated altitude rate resulting in no difference in gains required to account for altitude rate errors.

The gains were optimized with ± 20% variations applied to the lift coefficient resulting in no difference in gains required to account for uncertainty in lift.

5.0 CONCLUSIONS

The following conclusions can be made concerning guidance gain requirements during entry:

1. The current value of C17 proved to be satisfactory.
2. As seen in Figure 4 a higher value of C16 is required in the transition phase of entry at the higher drag acceleration levels compared to the same drag acceleration levels reached in the other entry phases.
3. C16 and C17 are insensitive to roll acceleration in the range of .85 to 1.0 deg/sec^2.
4. The gains, as optimized, perform adequately with navigated altitude rate errors in the range of $\pm$ 40 feet per second.
5. The gains, as optimized, perform adequately with lift uncertainties of $\pm$ 20%.

TABLE I. - STUDY POINT INITIAL CONDITIONS

STUDY POINT	ENTRY PHASE	VELOCITY FPS	ALTITUDE, FT.	DRAG ACCELERATION, FPS^2	BANK ANGLE
1	Transition	6,572	133,964	22.9	-42°
2	Transition	3,668	102,127	19.8	-37°
3	Constant-heat-rate	24,995	243,315	10.0	-73°
4	Constant-heat-rate	22,248	225,801	16.2	-63°
5	Equilibrium-glide	20,050	211,503	22.8	-59°
6	Constant-g	13,992	188,618	25.2	-44°

TABLE II. RANGE OF ACCEPTABLE VALUES AND OPTIMUM VALUES FOR C16 AND C17

STUDY POINT	ENTRY PHASE	C16			C17		
		MINIMUM	OPTIMUM	MAXIMUM	MINIMUM	OPTIMUM	MAXIMUM
1	TRANSITION	.080	.150	.200	.0020	.0025	.0035
2	TRANSITION	.070	.080	.100	.0020	.0025	.0030
3	CONSTANT HEAT-RATE	.100	.200	.300	.0030	.0040	.0050
4	CONSTANT HEAT-RATE	.075	.100	.125	.0022	.0025	.0028
5	EQUILIBRIUM GLIDE	.060	.080	.100	.0023	.0025	.0027
6	CONSTANT-G	.070	.080	.120	.0022	.0025	.0026

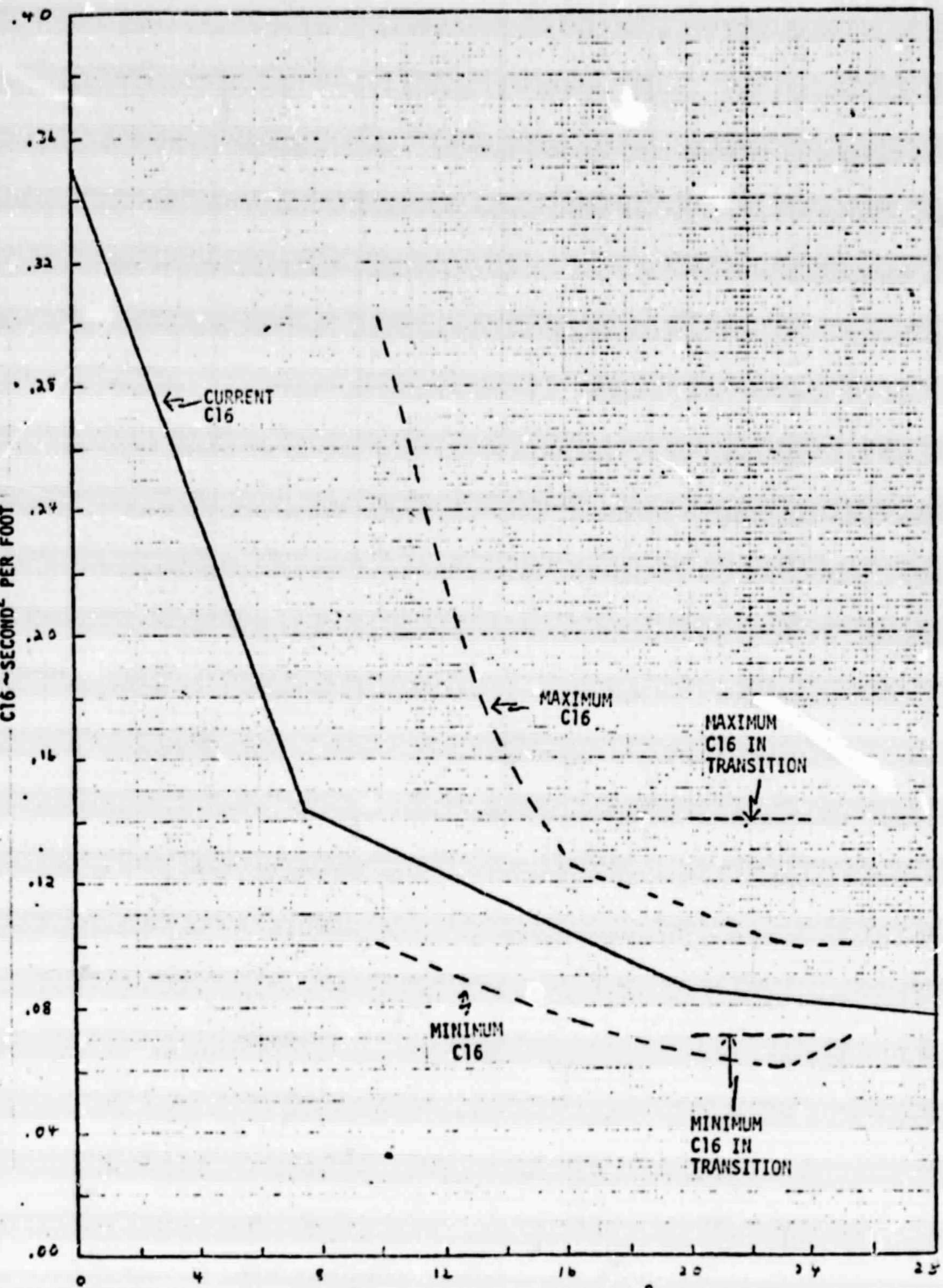

FIGURE 4. - RANGE OF OPTIMIZED C16 AND CURRENT C16.

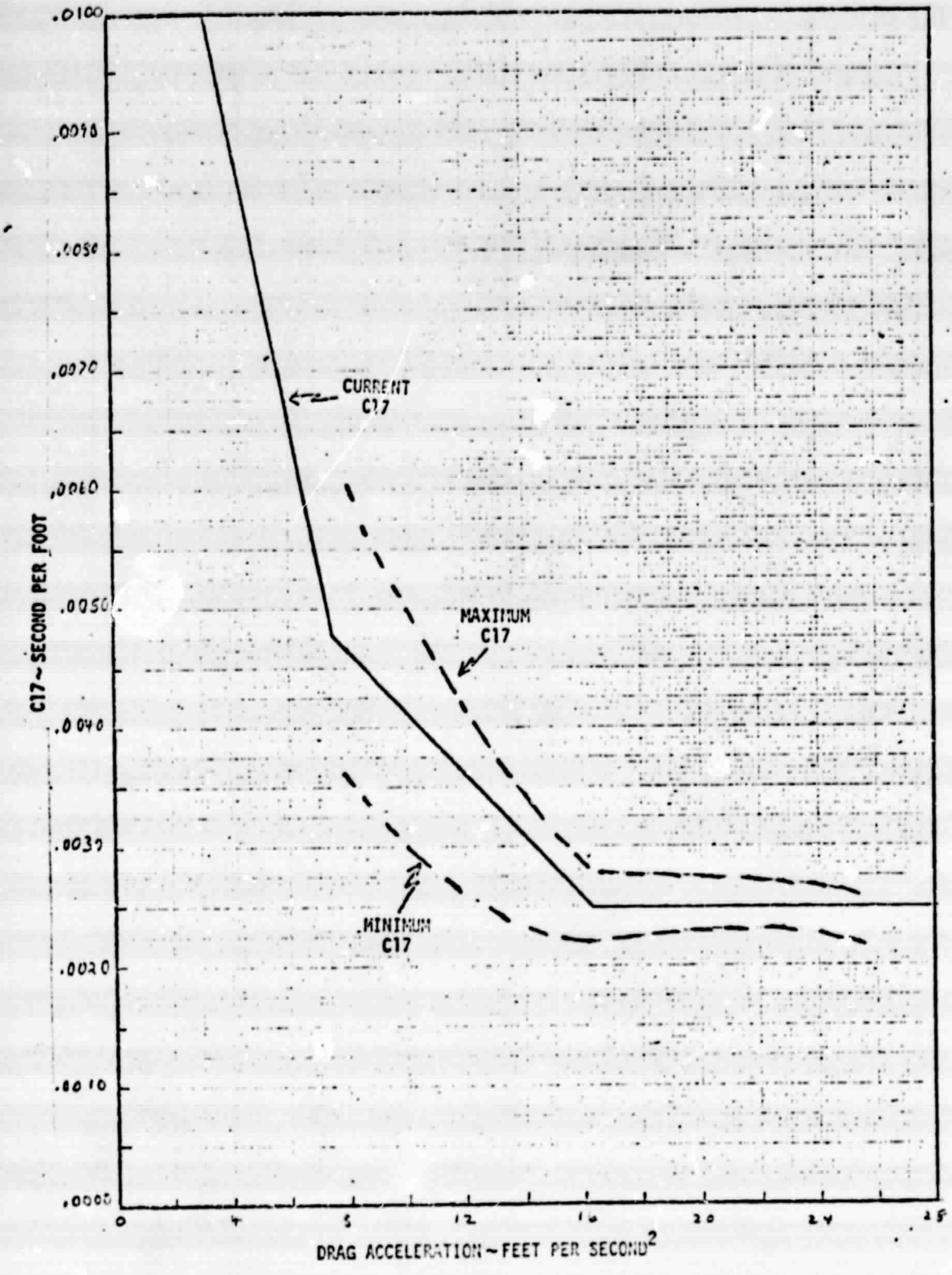

FIGURE 5. - RANGE OF OPTIMIZED C17 AND CURRENT C17.

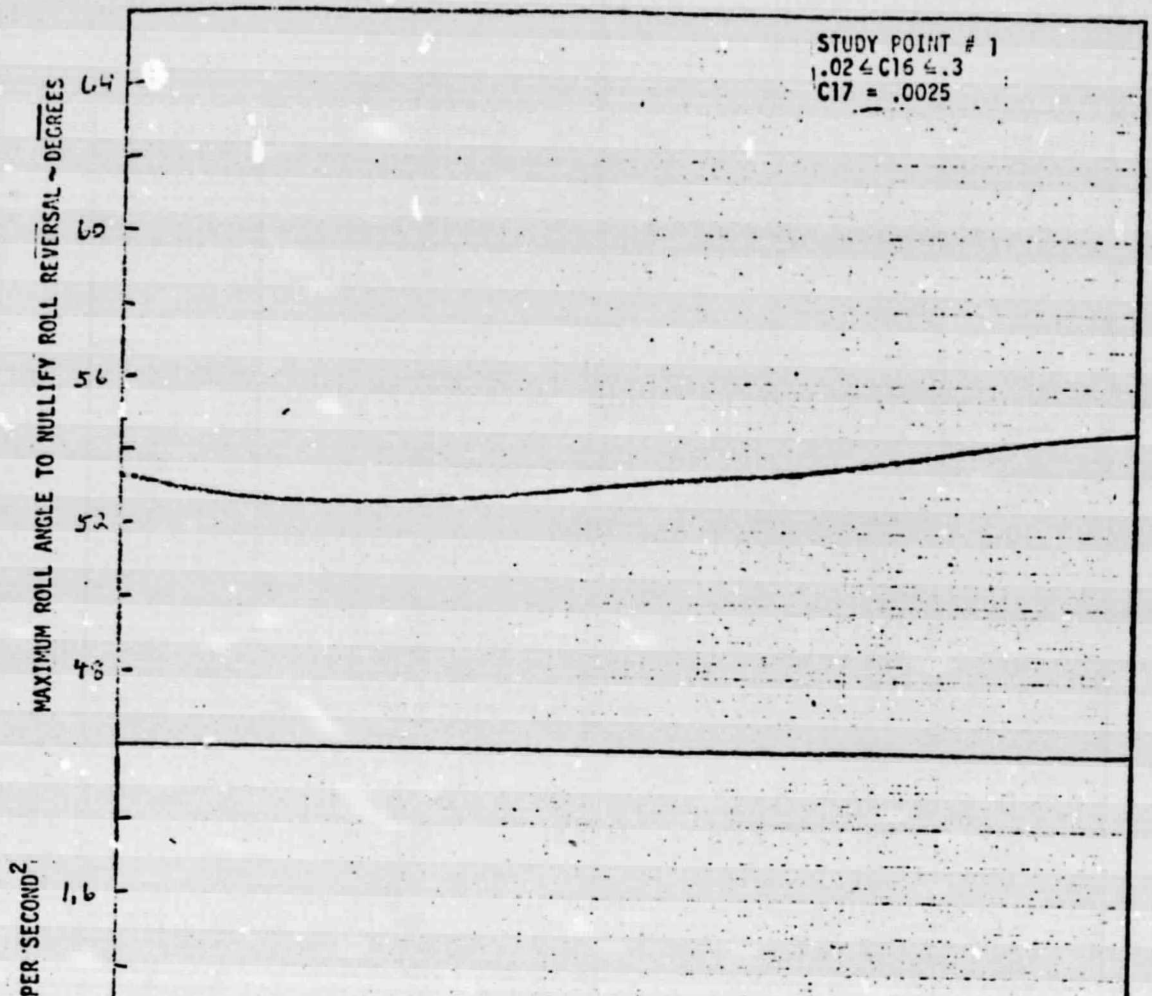

FIGURE 6. - EFFECTS OR ROLL REVERSAL ON STUDY POINT 1 - OPTIMIZING C16.

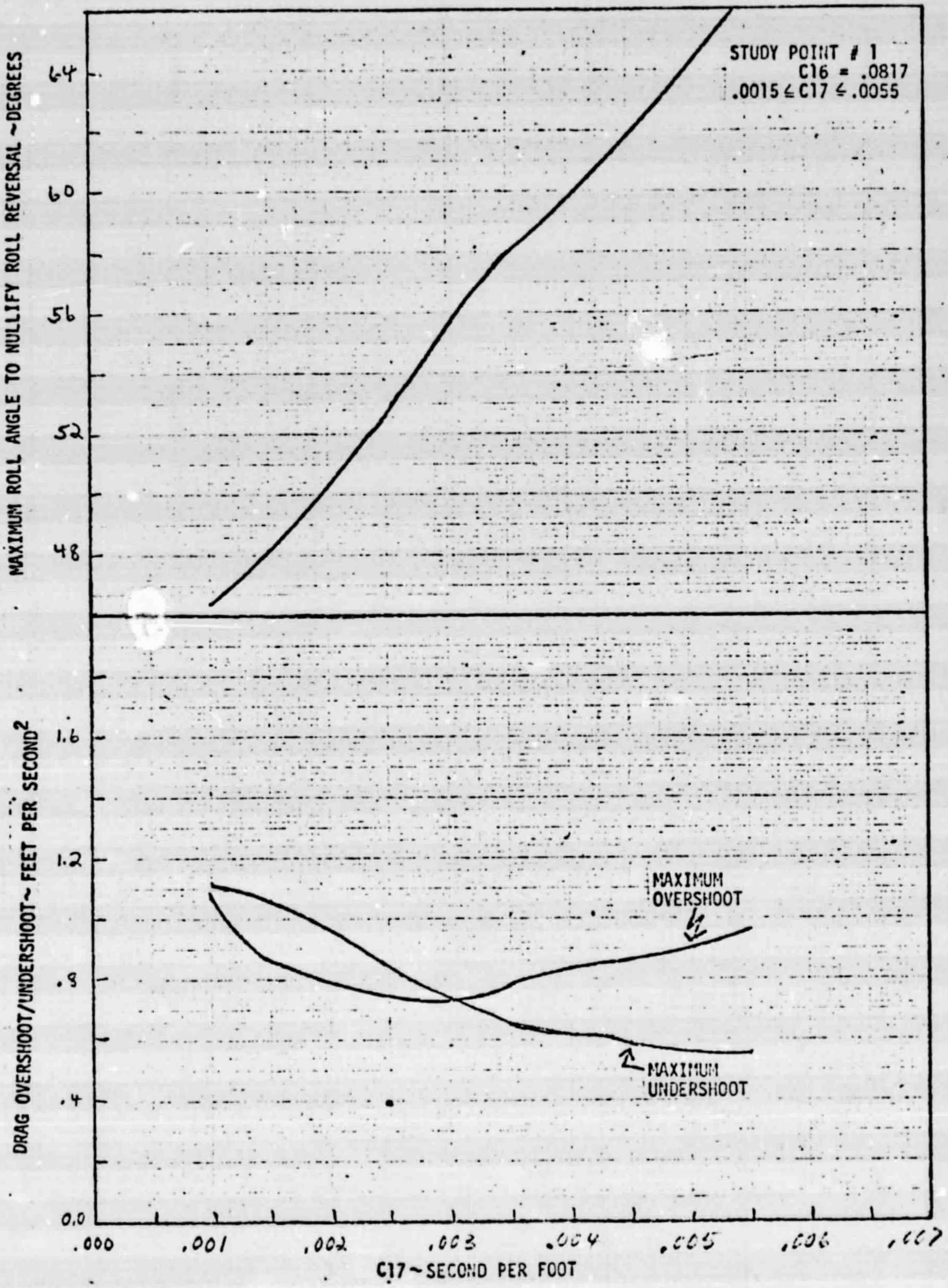

FIGURE 7. - EFFECTS OF ROLL REVERSAL ON STUDY POINT 1 - OPTIMIZING C17.

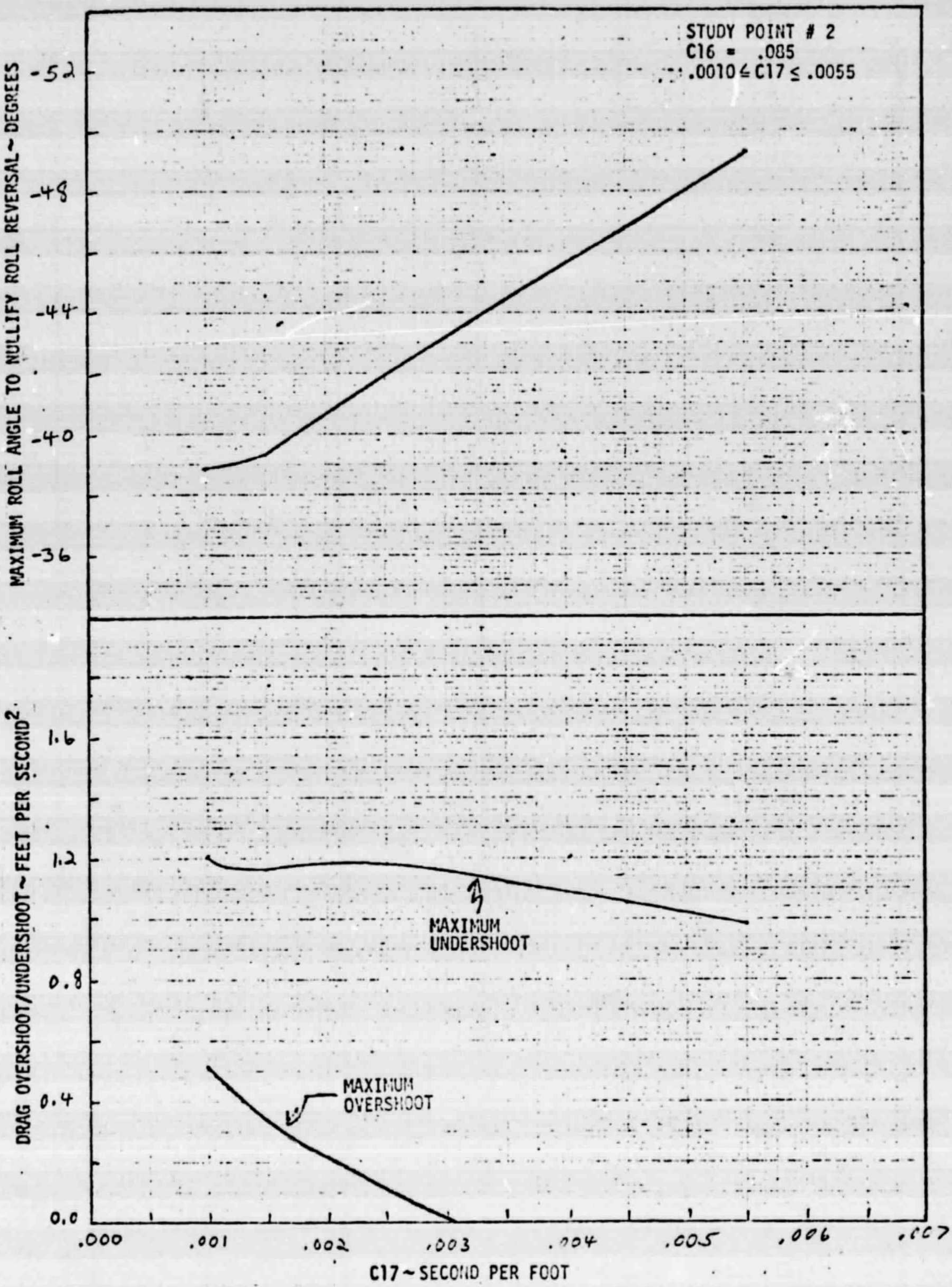

FIGURE 8. - EFFECTS OF ROLL REVERSAL ON STUDY POINT 2 - OPTIMIZING C17.

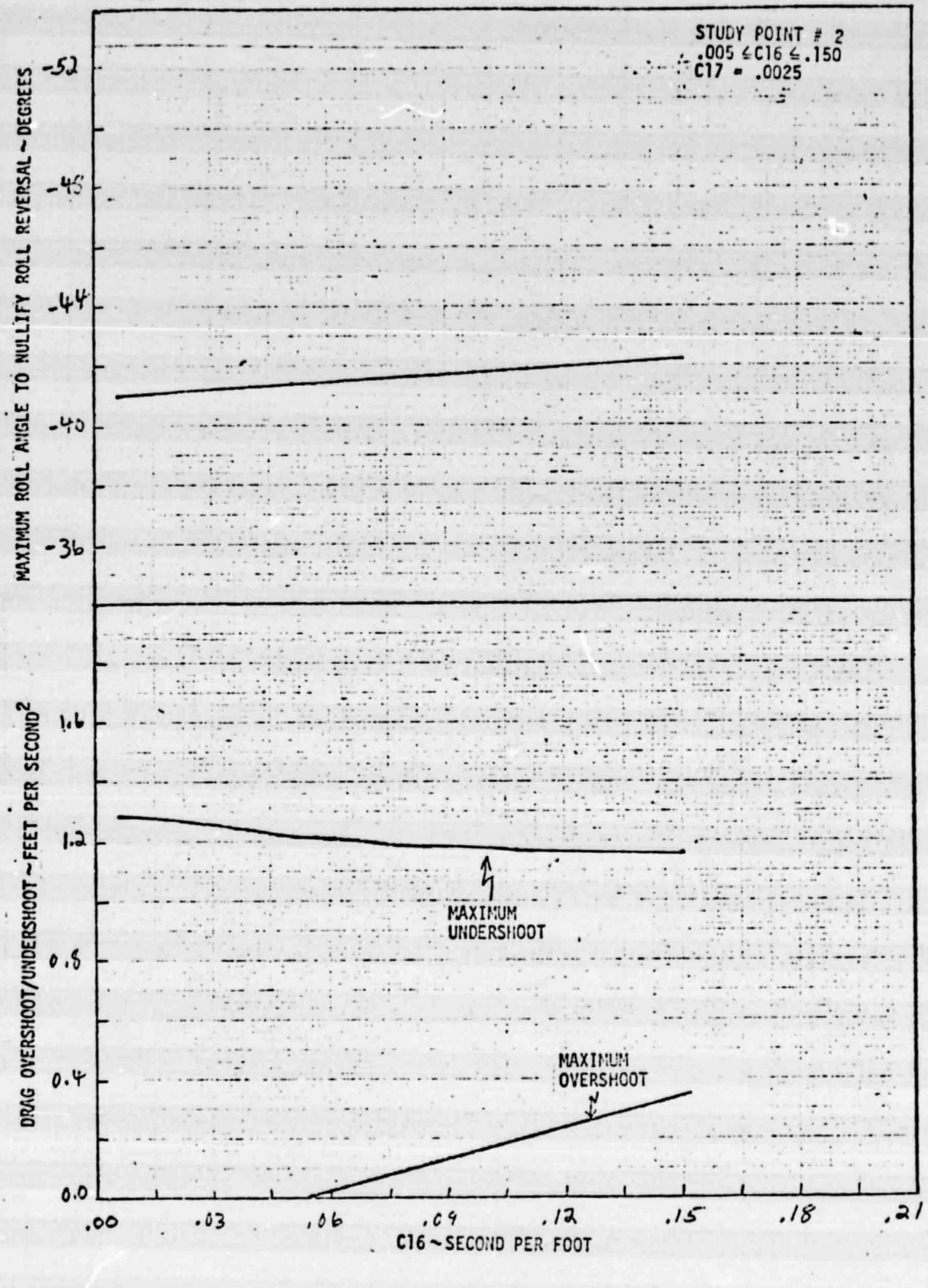

FIGURE 9. - EFFECTS OF ROLL REVERSAL ON STUDY POINT 2 - OPTIMIZING C16.

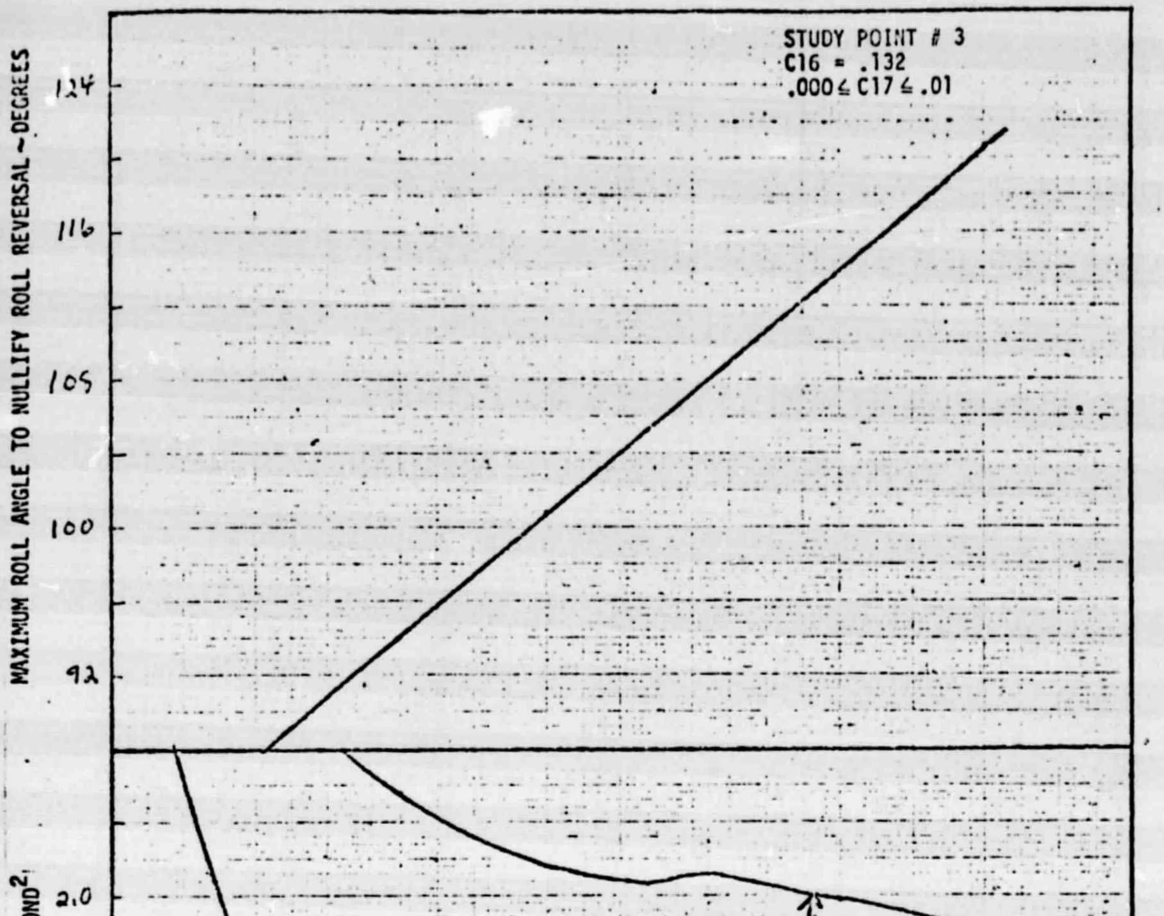

FIGURE 10. - EFFECTS OF ROLL REVERSAL ON STUDY POINT 3 - OPTIMIZING C17.

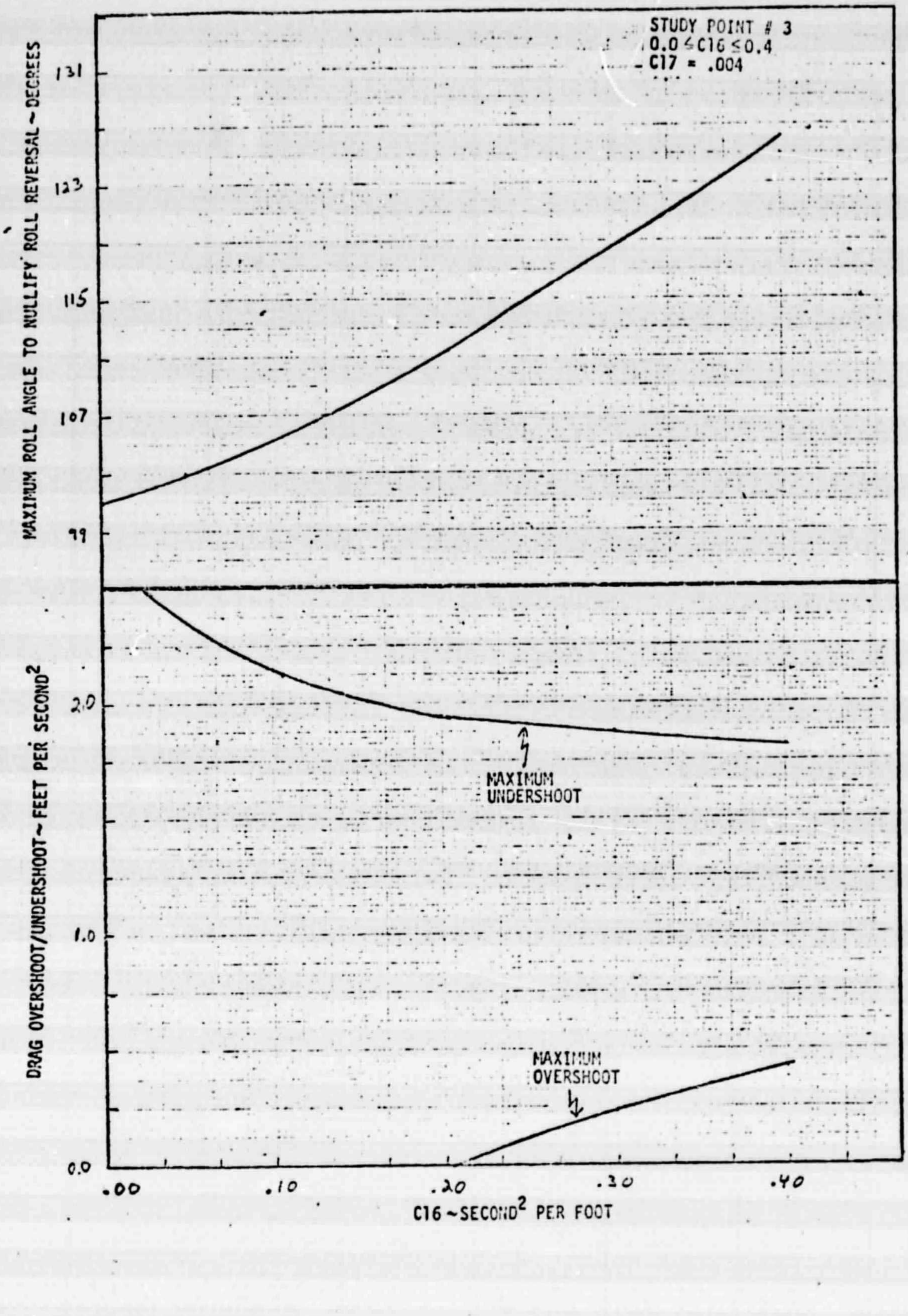

FIGURE 11. - EFFECTS OF ROLL REVERSAL ON STUDY POINT 3 - OPTIMIZING C16.

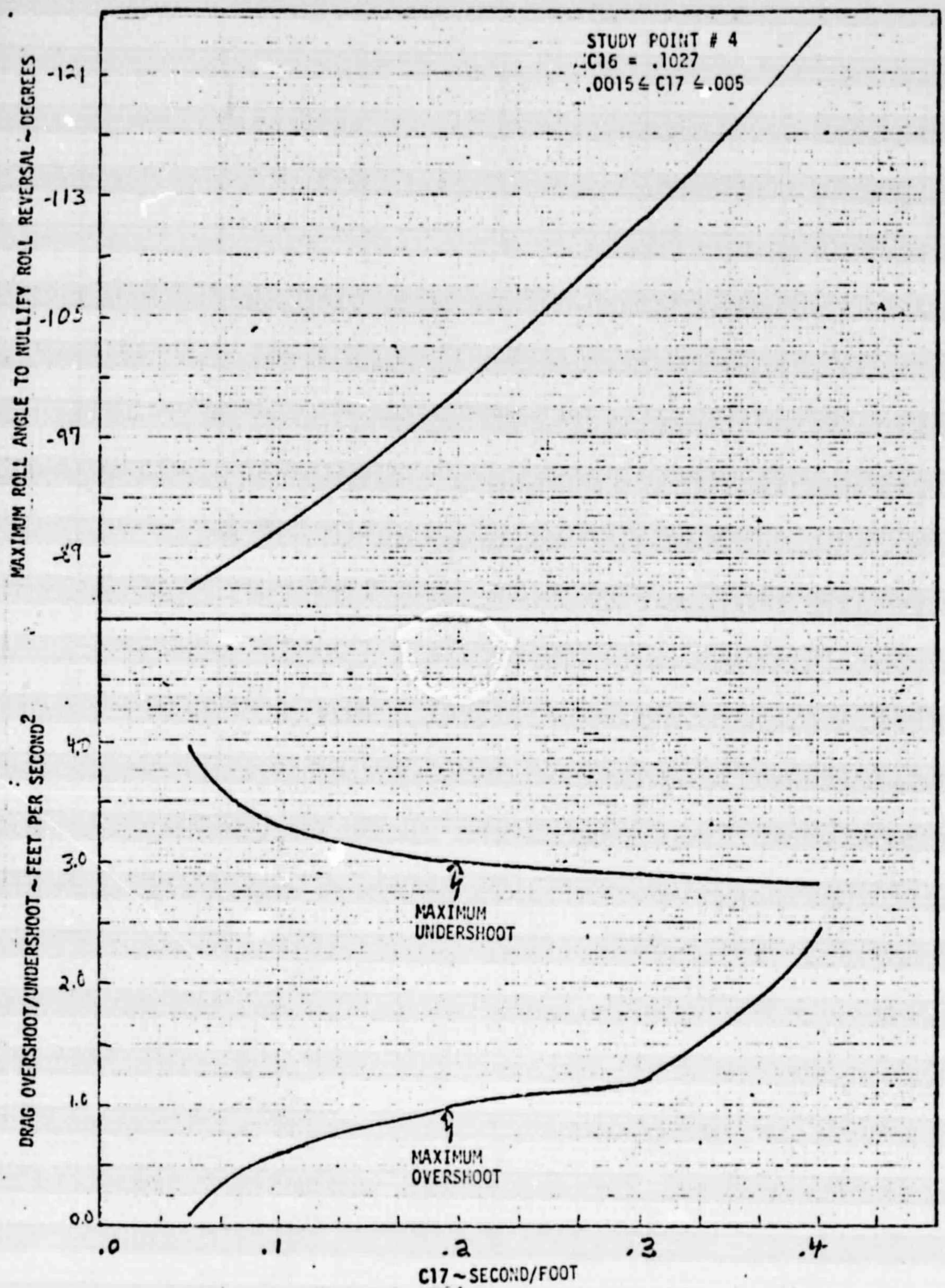

FIGURE 12. - EFFECTS OF ROLL REVERSAL ON STUDY POINT 4 - OPTIMIZING C17.

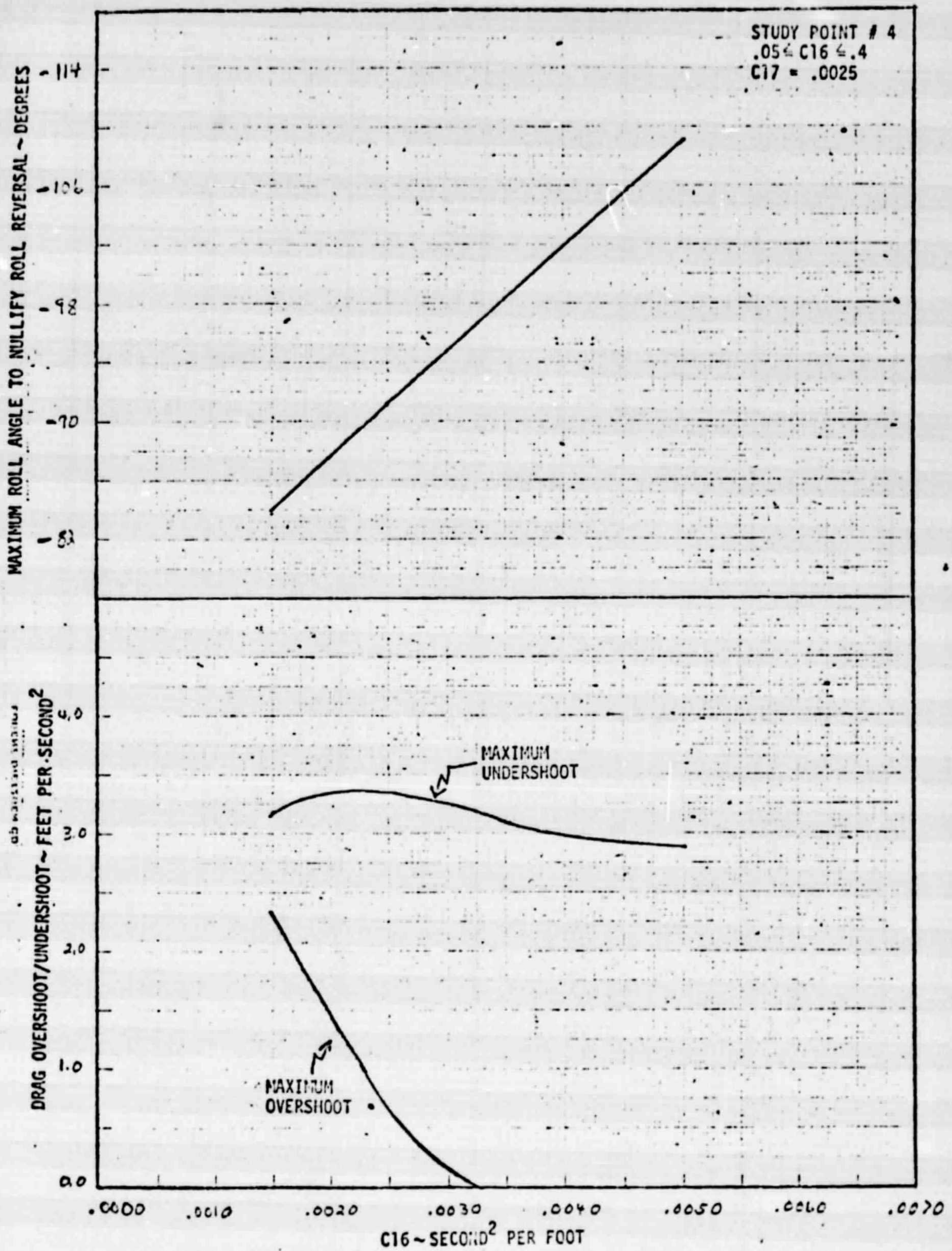

FIGURE 13. - EFFECTS OF ROLL REVERSAL ON STUDY POINT 4 - OPTIMIZING C16.

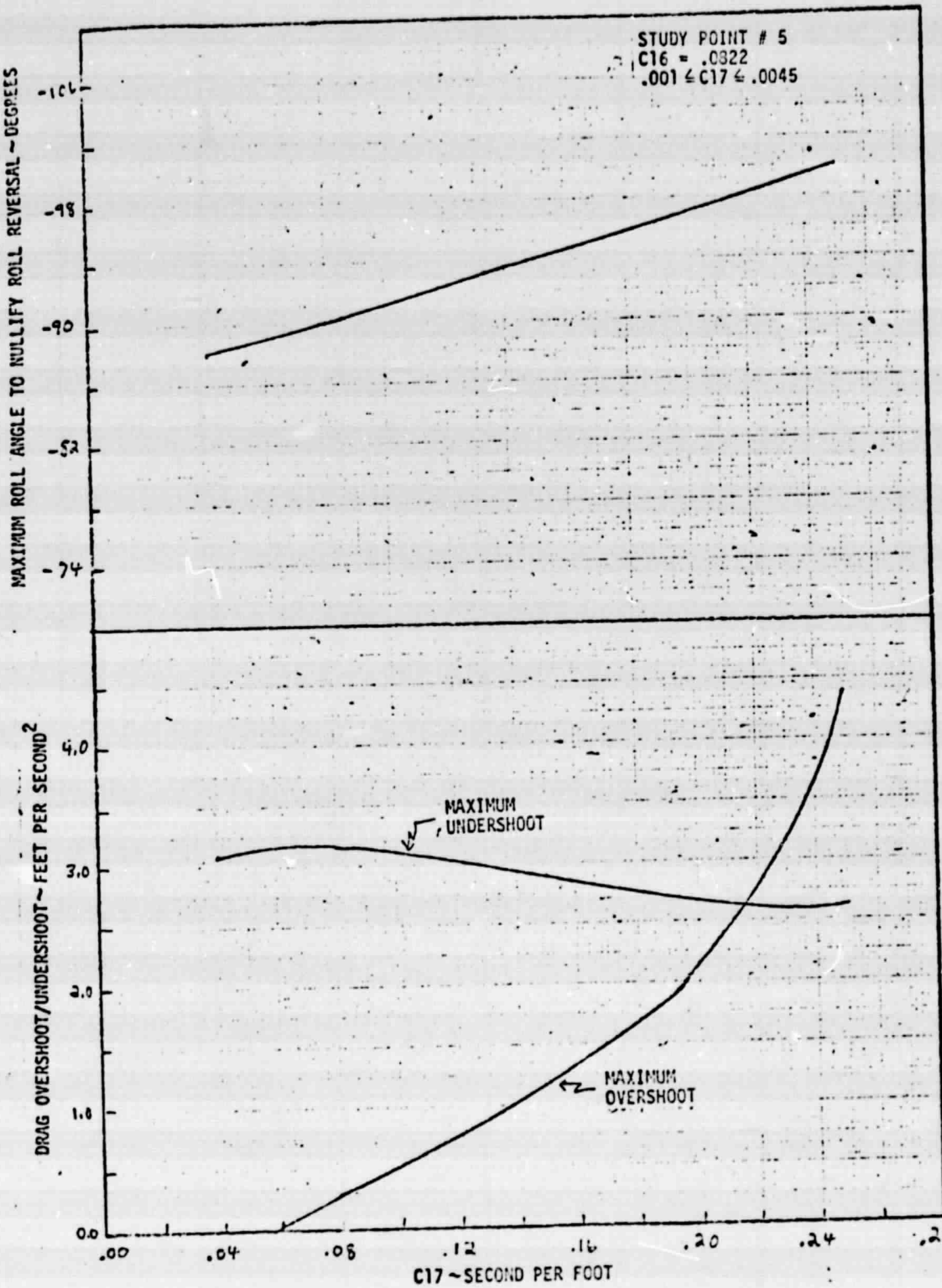

FIGURE 14. - EFFECTS OF ROLL REVERSAL ON STUDY POINT 5 - OPTIMIZING C17.

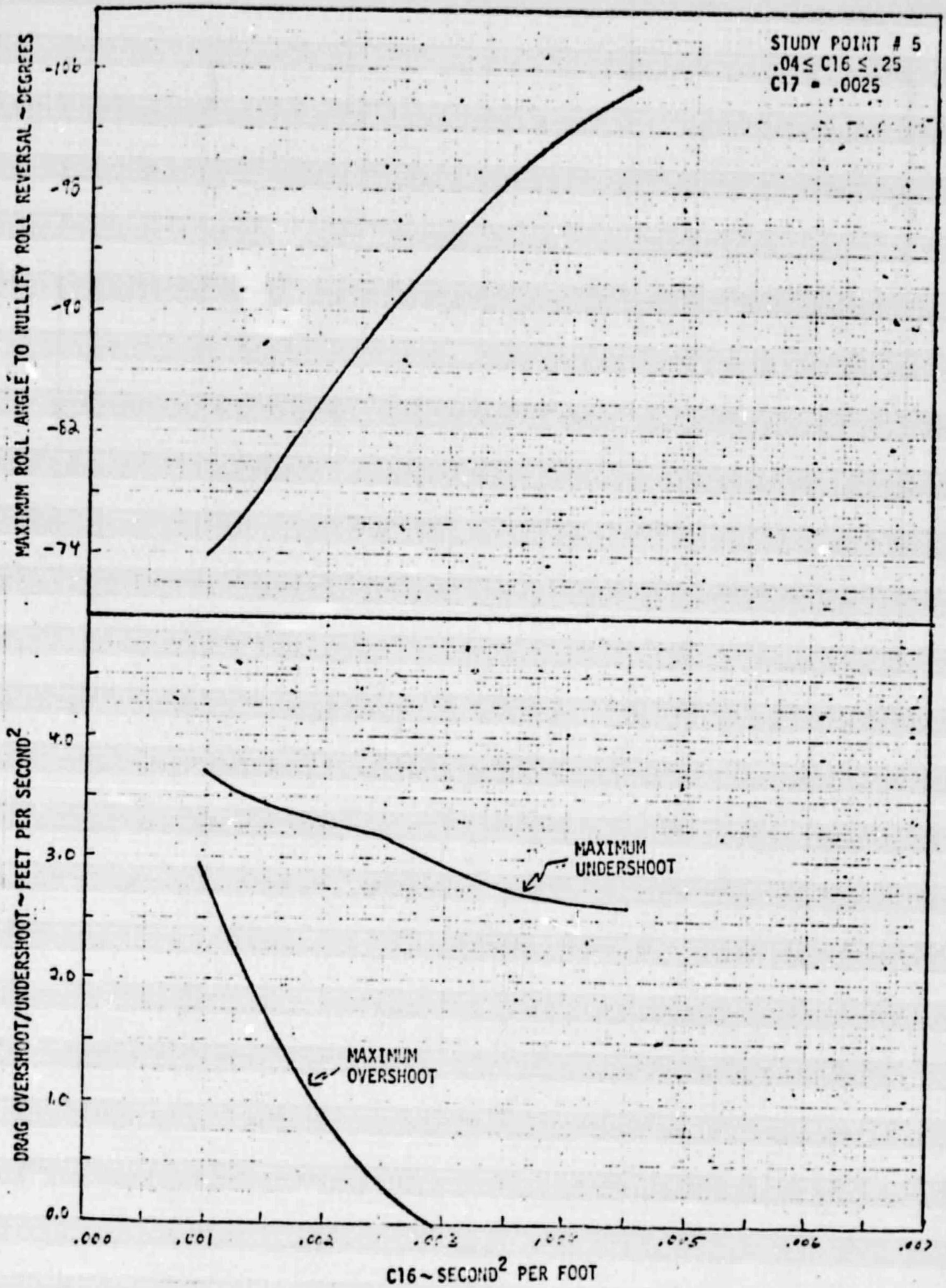

FIGURE 15. - EFFECTS OF ROLL REVERSAL ON STUDY POINT 5 - OPTIMIZING C16.

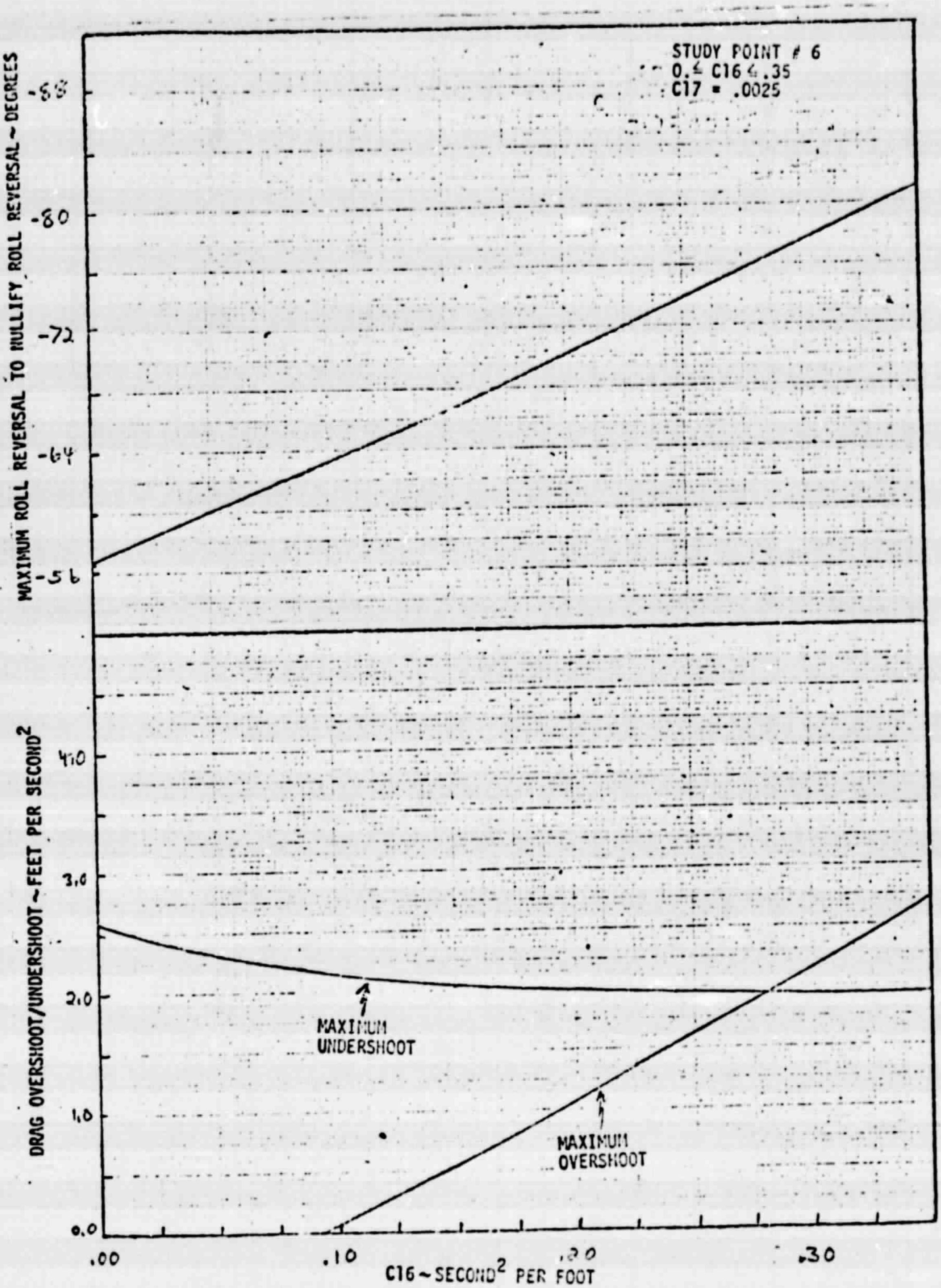

FIGURE 16. - EFFECTS OF ROLL REVERSAL ON STUDY POINT 6 - OPTIMIZING C16.

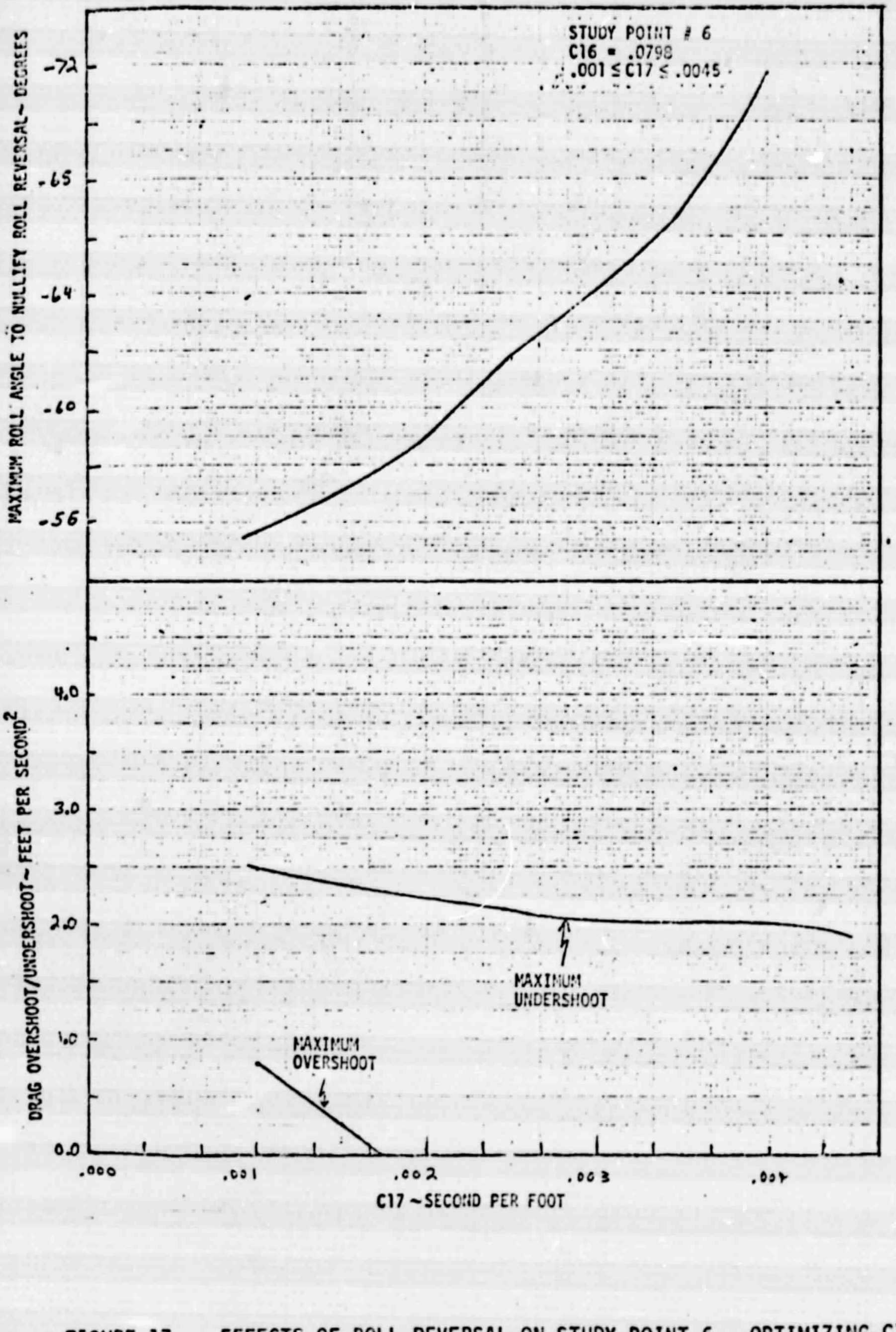

FIGURE 17. - EFFECTS OF ROLL REVERSAL ON STUDY POINT 6 - OPTIMIZING C17.

6.0 REFERENCES

1. Harpold, Jon C.: "Control System Requirements for Trajectory Control During Entry". JSC Internal Note No. 73-FM-84, 24 May 1973.

2. Harpold, Jon C.: "Analytic Drag Control Entry Guidance System". JSC Internal Note No. 74-FM-25, 15 April 1974.