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FLIGHT TEST DATA FOR LIGHT AIRCRAFT SPOILER ROLL CONTROL SYSTEMS

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INTRODUCTION

Spoilers are widely used for primary or supplementary roll control on large, multi-engine jet aircraft. They are invariably actuated by irreversible powered control systems. Thus, any non-linearities in hinge moments or rolling moments can be disguised from the pilot by properly tailoring the system.

Unfortunately, there has been until recently a dearth of spoiler design information in the open literature which would be useful to the light airplane designer. Only one general aviation airplane, the high performance, twin turboprop Mitsubishi MU-2, employs spoilers for roll control.

There are several reasons for using spoilers rather than ailerons for roll control:

1. Spoilers permit the use of full span trailing edge flaps. This permits higher wing loading and corresponding improvements in cruise performance and ride quality (1).

2. Spoilers can be designed to eliminate adverse yaw (1, 2, 3)*.

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*Numbers in parentheses designate References at end of paper.

ABSTRACT

The results of flight tests to determine the characteristics of spoiler roll control systems on three different light aircraft are summarized. Comparisons are made with wind tunnel data where available. Flight tests indicate that excellent roll characteristics can be achieved with spoilers. Yaw coupling with roll control inputs is virtually eliminated. Roll rates remain high when flaps are deployed at low speed. Very mild nonlinearities in control effectiveness exist and there was no deadband or lag detected.

3. Spoilers can be designed in conjunction with flap systems such that roll power remains high at approach speeds, rather than becomes sluggish as with ailerons (2, 3).

4. Spoilers, once installed, can be incorporated into a flight path control system which offers easier and more accurate control during final approach (4).

Three experimental flight test projects have recently been completed which provide valuable data on spoiler roll control systems installed on light aircraft. Each of the systems is unique. The projects were conducted by the University of Kansas Center for Research, Inc. with the sponsorship of the NASA Langley Research Center under grants NGR 17-002-072 and NSG 1227.

There have also been numerous wind tunnel studies conducted over the past few years which provide helpful data for the designer (5-11).

The purpose of this paper is to summarize the most important results of the three flight test programs and to compare them with wind tunnel data where available.

Nomenclature

b	wing span
c	wing chord
c_s	distance from hingeline to trailing edge of spoiler
C_H	hinge moment coefficient
C_ℓ	rolling moment coefficient
C_L	lift coefficient
Δh	height of spoiler trailing edge above wing upper surface, $c_s \sin \delta_s$
p	roll rate
V_c	calibrated airspeed
V_T	true airspeed
Y_i	spanwise location of inboard end of spoiler
Y_o	spanwise location of outboard end of spoiler
α	angle of attack
β	sideslip angle
δ_f	flap deflection
δ_s	spoiler deflection
ϕ	roll angle

Redhawk

The Redhawk is a Cessna Cardinal with new wings incorporating a 37% wing area reduction, Fowler flaps, Kruger flaps, and spoilers for roll control and flight path control. Complete flight test data on the Redhawk, including roll performance, is published in Ref. 12. A planview of the spoiler location is shown in Fig. 1. Only the outboard spoilers are used for roll control.

Figure 2 shows the spoiler cross-section and geometric data. There is a 0.4 inch gap between the hingeline and leading edge of the spoiler, but no direct venting from the undersurface of the wing to the spoiler cavity. The entire span of the roll spoilers is in front of a fixed aileron with the Fowler flap completely inboard of the spoiler.

The spoilers are actuated by a cam and pushrod linkage which deflects one spoiler while holding the other in a fixed flush position. The cam is connected by cable to the pilot's control wheel.

Roll performance was determined by initiating steady state roll rates with many different values of step spoiler inputs with a clean configuration and with full Fowler flap and Kruger flap deflections.

Figure 3 presents the flight test results for the Redhawk in terms of roll rate as a function of spoiler deflection. Figure 4 converts the roll rate data to roll helix angle, $pb/2V_T$. Figure 5 shows time histories of both low and high speed roll response.

Several characteristics are apparent. Roll rate is very nearly a linear function of spoiler deflection. Roll rates are adequate for good handling qualities, even though only a relatively small spoiler span is used. There is no perceptible yawing moment produced by spoiler deflection. Pilots reported that there was no lag in rolling moment following a step spoiler input.

There is a decrease in roll helix angle, $pb/2V_T$, when flaps are deployed, primarily because of the inboard shift of the lift distribution, giving the spoilers a smaller fraction of the total lift to spoil.

A series of design charts to predict spoiler effectiveness are presented in Refs. 5 and 6. Figure 6 illustrates the curve used to predict spoiler effectiveness, $C_{\ell_{\delta_s}}$, for the Redhawk. Although aspect ratio and taper ratio are not exactly matched, the similar lift distributions for straight tapered wings should give reasonably close results. The steady state roll equation

$$\frac{\dot{\phi}}{\delta_s} = - \frac{C_{\ell_{\delta_s}}}{C_{\ell_p}} \frac{2V_T}{b}$$

was used to determine $C_{\ell_{\delta_s}}$ from flight test data, with C_{ℓ_p} determined analytically from Ref. 13.

Assuming that for slightly different spoiler chords, equal spoiler deflection heights, h/c, produce equal rolling moments, the predicted roll power is calculated from Fig. 6 and compared to flight test results in Table 1. There is agreement to two figures for the clean wing, while the wind tunnel data with a straight taper over-predicts the flaps down roll power for the airplane because of the inboard shift in loading caused by the Fowler flaps.

Table 1. Summary of Lateral Control Power for the Redhawk

	$C_{\ell_{\delta_s}}$ Clean Wing	$C_{\ell_{\delta_s}}$ Full Flaps Deployed
Flight test results using steady state roll approximation	0.042 rad^{-1}	0.025 rad^{-1}
Predicted from wind tunnel data, Ref. 5.	0.042	0.037

The rolling moment characteristics of the Redhawk spoilers are similar in nature to the data reported by Wentz (10) from two-dimensional wind tunnel tests of an unvented spoiler on a clean GA(W)-1 airfoil, Fig. 7.

No wheel force data were recorded for the Redhawk; however, all pilots reported a positive centering force for the spoilers under all flight conditions. This is to be expected from the wind tunnel hinge moment data presented in Fig. 7 which shows no floating tendency at zero spoiler deflection. Even though the aerodynamic hinge moment slope is quite flat for small deflections, the weight of the spoiler provides an adequate centering moment in this region.

Advanted Technology Light Twin (ATLIT)

The ATLIT is a Piper Seneca with completely new wings incorporating reduced wing area, full-span Fowler flaps, a GA(W)-1 airfoil, and spoilers for roll control. A complete description of the airplane and the flight test program is contained in Ref. 3.

The ATLIT spoilers are similar to those on the Redhawk, except in the flaps-down condition, when there is direct venting from the lower surface through the flap cavity, and the spoilers are, of course, in front of the full-span flaps. The spoiler installation is illustrated in Fig. 8. The spoilers each have a span of 49.6% of the wing semispan and a chord of 3.5 in, which averages approximately 9% of the wing chord. There is a 0.62 in. gap between the spoiler hinge line and the leading edge of the spoiler.

As expected, the roll rates with flaps nested, Fig. 9, are nearly linear with spoiler deflection, as with the Redhawk, and predicted by wind tunnel tests of the ATLIT configuration, Fig. 7. The spoiler effectiveness decreases as lift coefficient increases because of the shift in loading toward the leading edge.

With the Fowler flaps at 30° and 37° (Figs. 10 and 11), three significant changes take place. The increased loading aft of the spoiler offers a larger percentage of the lift to be affected by the spoiler, increasing the maximum rolling moment. The maximum helix angle is increased from .085 with flaps nested to .15 with flaps at 37°. Secondly, the spoilers become more effective as lift coefficient increases, opposite to the flaps nested case. Finally, there is a mild nonlinearity in the spoiler effectiveness. This characteristic was reported by Wentz (10) and wind tunnel data are shown in Fig. 12. Clearly, the nonlinearity was not nearly as severe for the airplane in flight as for the wind tunnel model.

A typical time history of an ATLIT roll maneuver is shown in Fig. 13. There is very little coupling between the yaw rate and spoiler deflection.

One troublesome characteristic is noted in Fig. 12, which shows a strong decentering hinge moment, or floating tendency, of the vented spoilers with flaps down. Very careful design is necessary to overcome this characteristic. Such features as having a down travel on one side while the other spoiler rises, and incorporating centering springs may be helpful. Raising the two spoilers symmetrically as the flaps deflect is another very effective technique for providing aerodynamic centering and avoiding the reduced spoiler effectiveness for small deflections.

Robertson Modified Seneca

The most recent spoiler system developed for application to light aircraft was designed by Robertson Aircraft Corp. as a modification to the Piper Seneca. The unique feature of this system is that it is a slot-lip spoiler. The trailing edge of the spoiler forms the slot-lip of the full-span Fowler flap.

The slot-lip spoiler has the advantage of providing nearly linear control effectiveness with the flaps down as well as up. It has the disadvantage of not allowing spoiler down travel with flaps up, because the spoiler rests against the leading edge of the flap. This was resolved by allowing the down traveling spoiler to elastically deform with the spoiler trailing edge against the flap. This provided a firm centering force with flaps up.

With flaps down the control linkage system changed so that both spoilers came up to a 6 degree deflection and increased the spoiler down travel. This arrangement eliminated the float-up problem illustrated in Fig. 12, and caused a high initial roll sensitivity with small deflections, resulting in excellent control characteristics.

The Robertson-Seneca spoiler installation is illustrated in Fig. 14. Flight test results are presented in Figs. 15-18. A complete description of the flight test program is found in Ref. 2.

Several conclusions may be drawn from these data. At low flap settings (0^o and 10^o) spoiler effectiveness increases as airspeed increases and C_L and α decrease. However, for $\delta_f \geq 20^o$ spoiler effectiveness appears to be virtually independent of C_L over the range tested.

Cable stretch characteristics of the system limited the maximum spoiler deflection at high airspeeds. The result is that maximum helix angle, $pb/2V_T$, is almost independent of airspeed for a given flap deflection.

Another important characteristic is the significant increase in maximum rolling moment available as flaps are deflected. Maximum rolling moment coefficient with $\delta_f = 40^o$ is 2.64 times that obtained with $\delta_f = 0^o$. Thus at low airspeeds the spoiler system can provide roll rates as high or higher than cruise roll rates.

For all flap settings and airspeeds there is no deadband or reduced sensitivity at small spoiler deflections. The zero airspeed bias spoiler setting of 6^o reduces to about 2.4^o in flight because of aerodynamic loads.

The qualitative yaw characteristics of the spoilers were determined by recording sideslip angle, β, during each roll maneuver. Fig. 19 shows two typical time histories. It appears that yawing moment due to spoiler deflection is very nearly zero for all flap settings and airspeeds tested.

Conclusions

1. Data from three flight test programs indicate that spoilers can be employed to obtain desirable roll control characteristics for light aircraft. However, the design task may be more difficult than for ailerons.

2. No deadband or severe reduction in sensitivity for small deflections was observed with any of the three systems tested.

3. When placed in front of a Fowler flap, spoiler control effectiveness increases with flap deflection.

4. There is a strong float-up moment acting on a vented spoiler at small spoiler deflections. This decentering moment must be counteracted in the system design to provide acceptable handling qualities.

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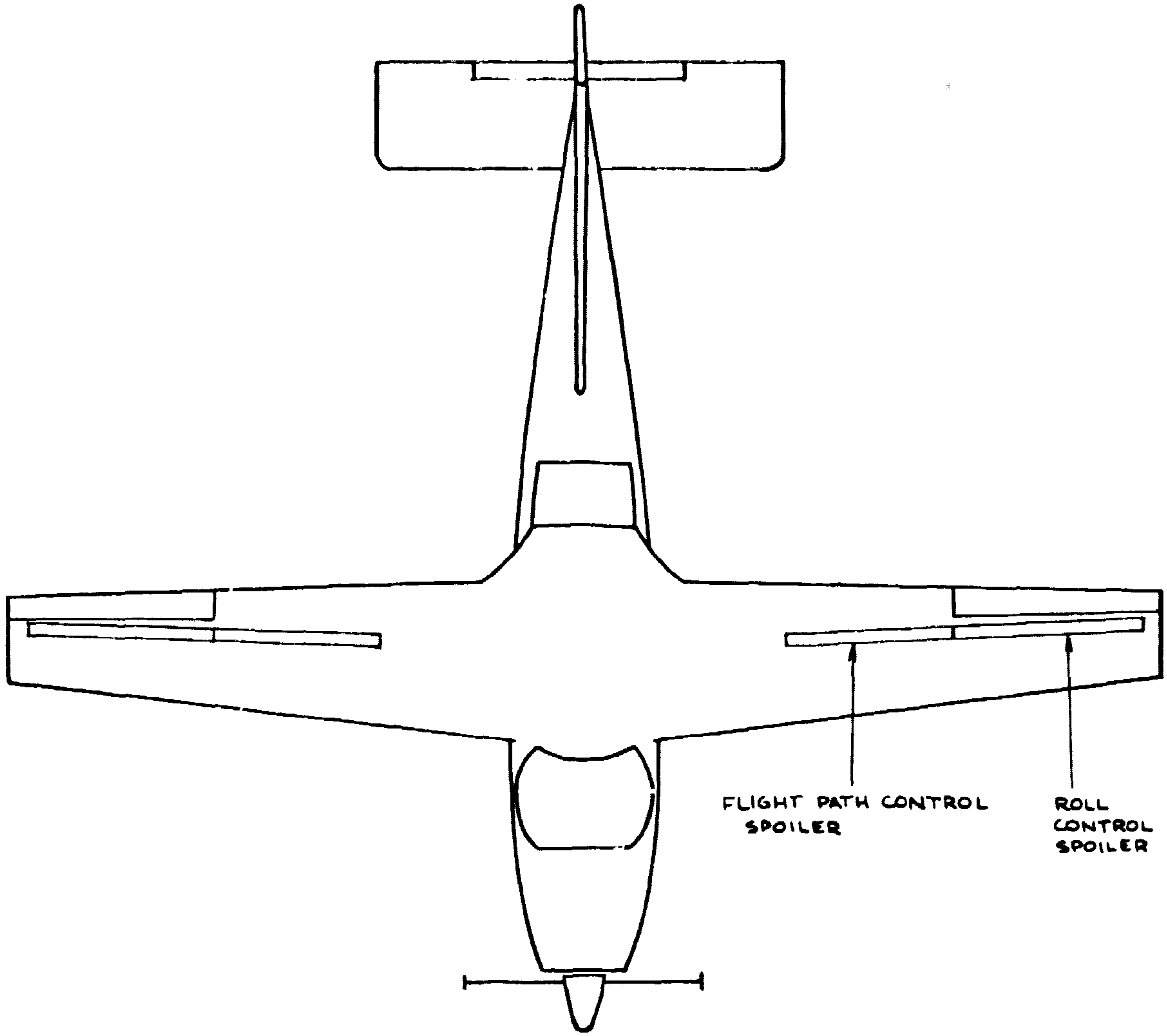


Spoiler Location on the Redhawk

Figure 1

Spoiler Span = 32% b/2

Y_i = 64.5%, Y_o = 96.5%

C_s = 4 in. including 0.4 in gap

Hingeline at 70% C

C_s/C_{ave} = 12.2%

$\delta_{s_{max}} = 60^o$

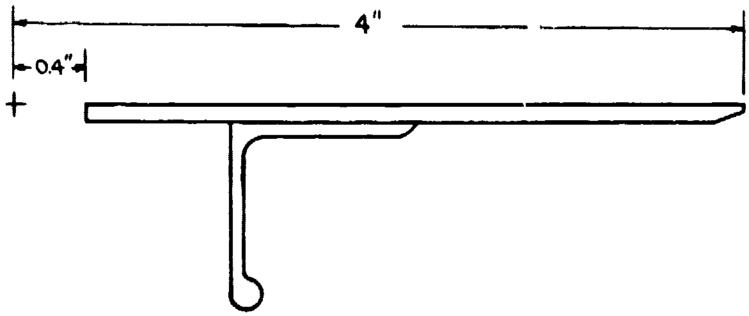
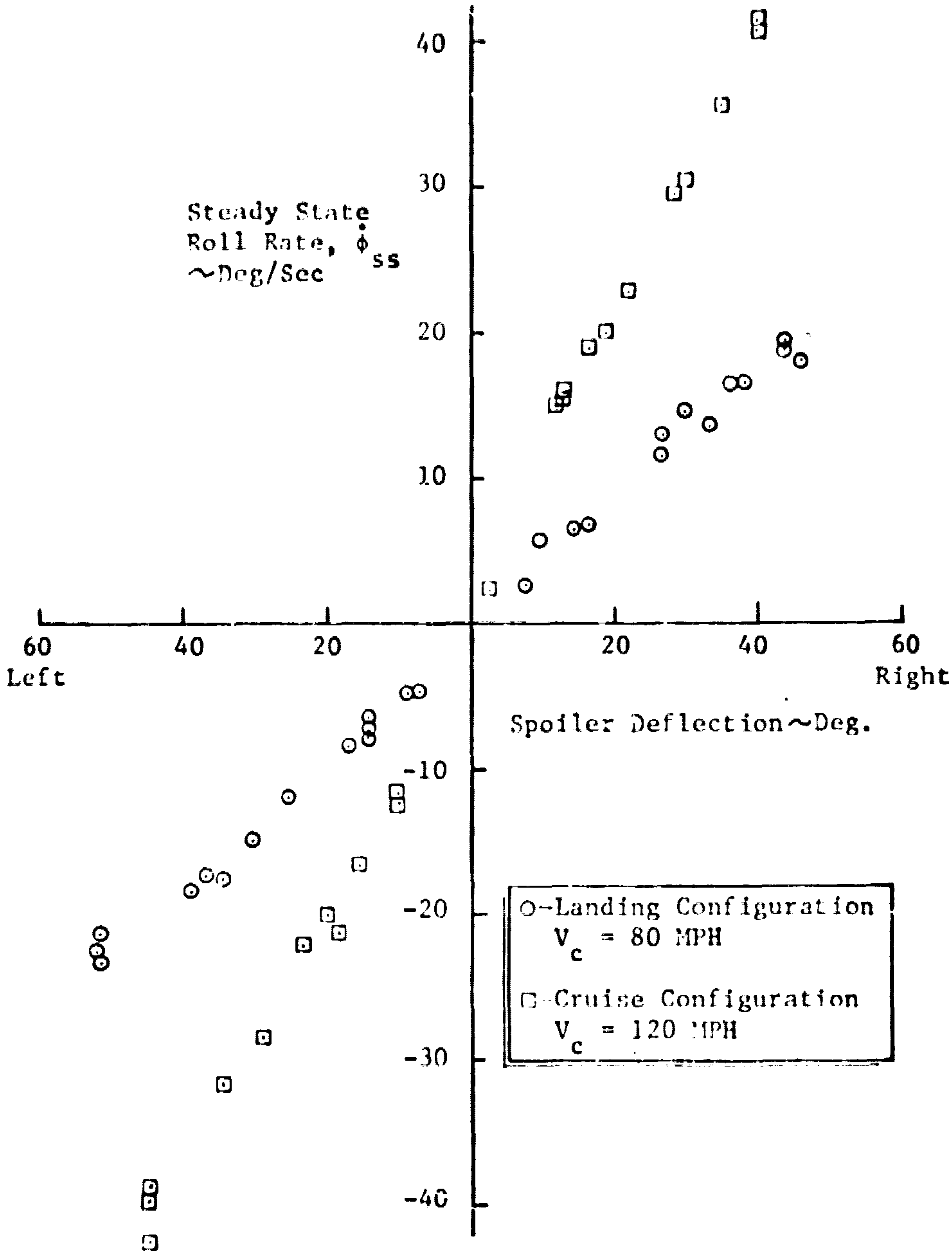


Figure 2. Redhawk Spoiler Data and Cross Section



Redhawk Steady State Roll Performance
(Outboard Spoilers Only)

Figure 3

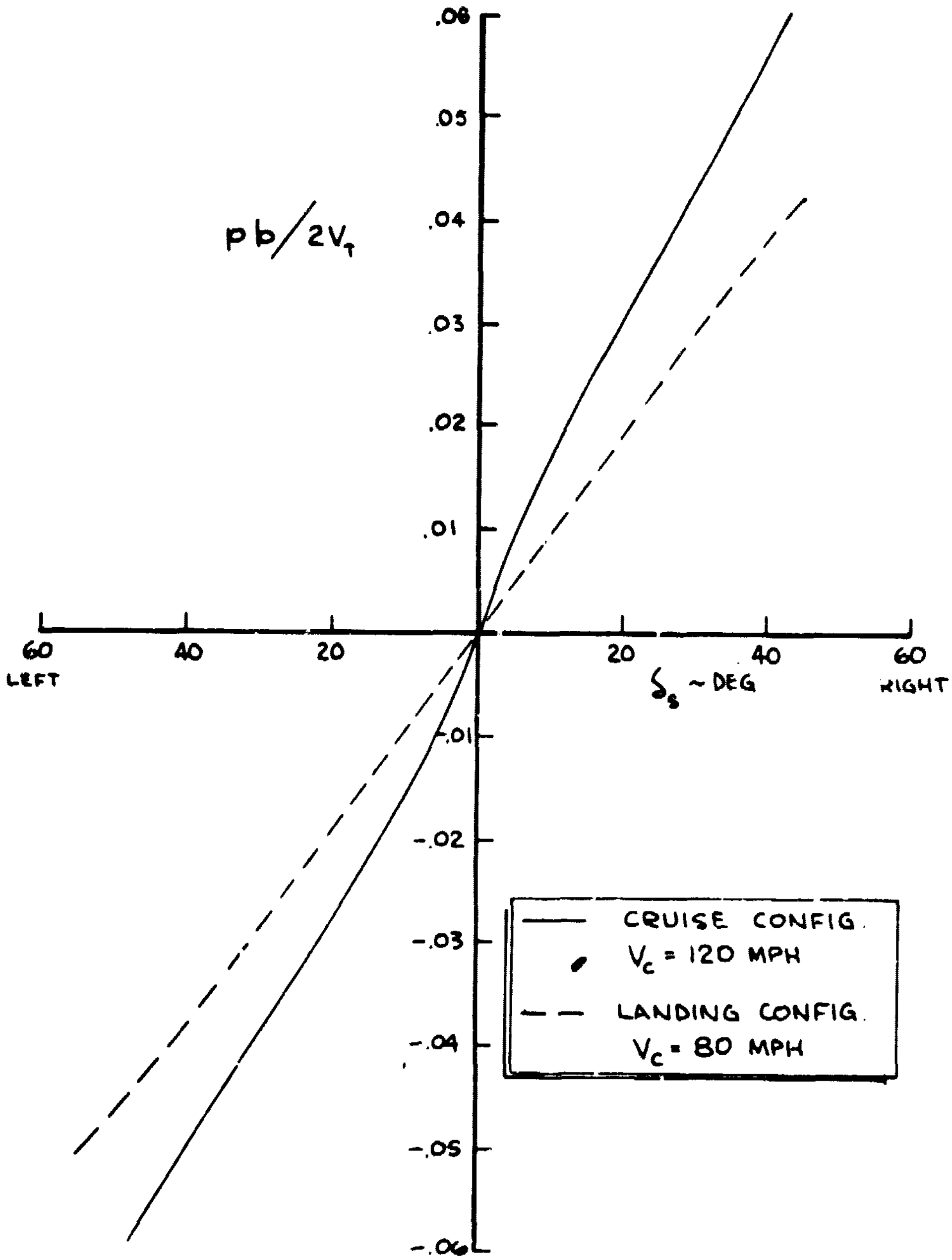


Figure 4. Steady State Roll Helix Angle, Redhawk

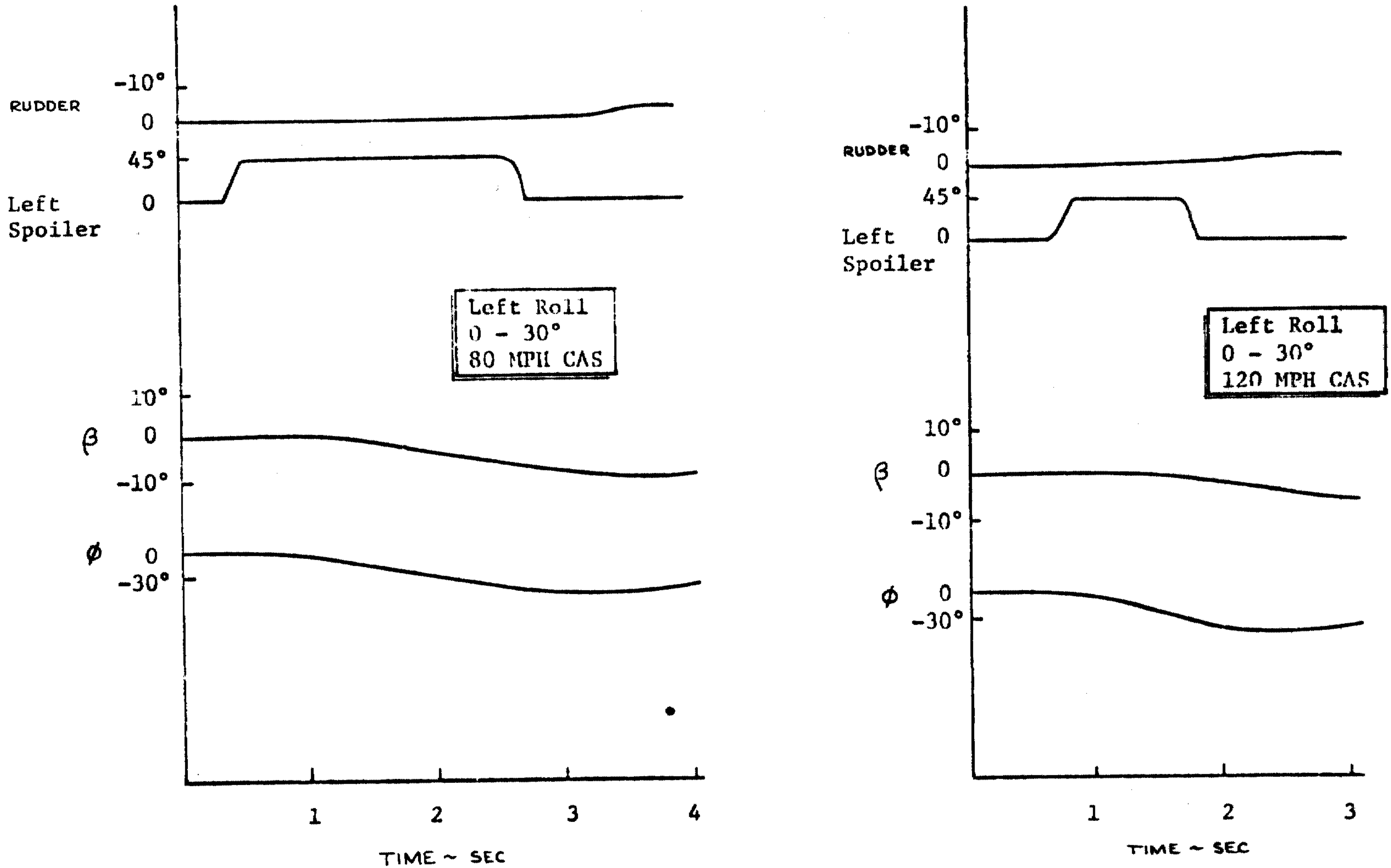
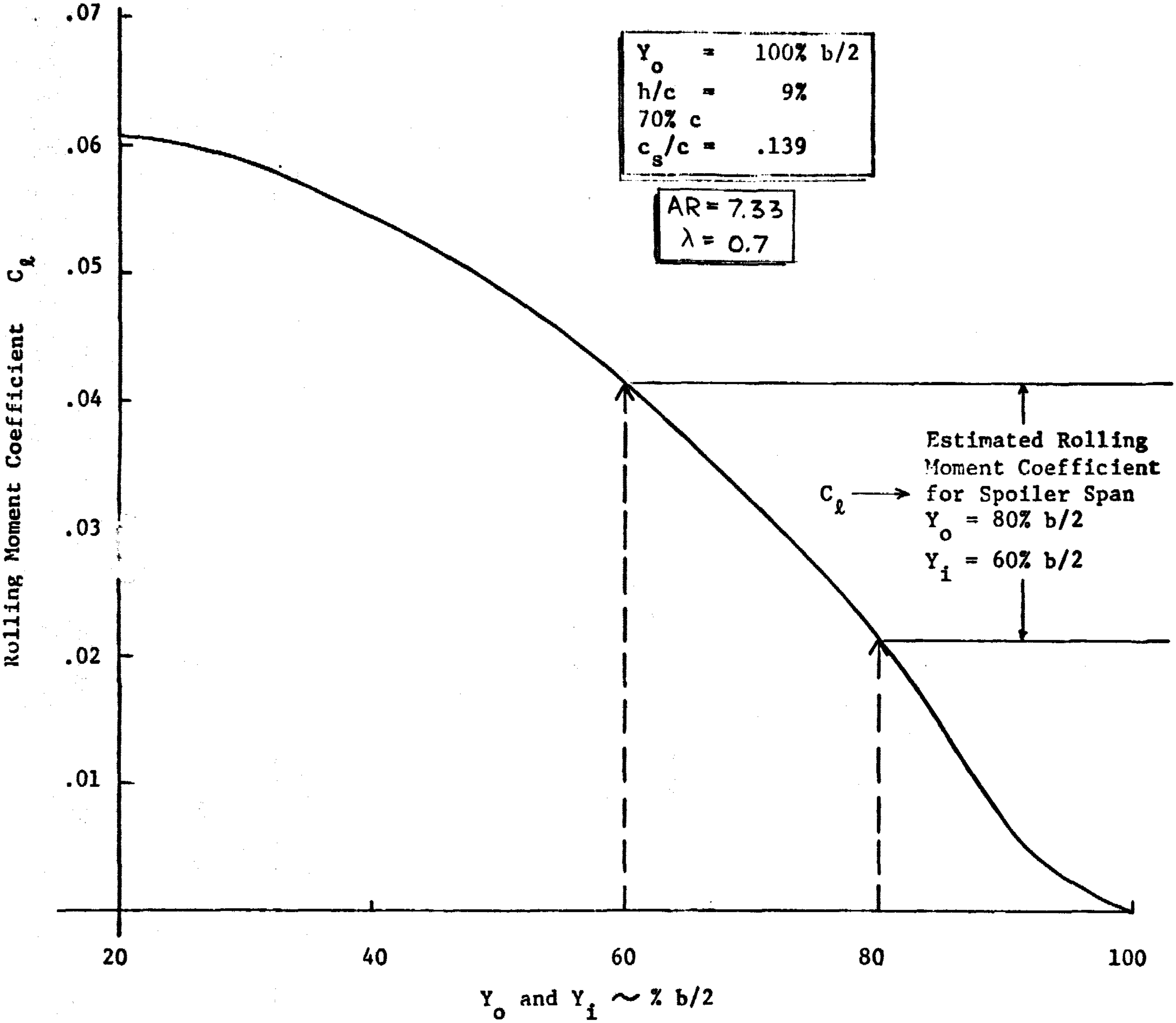
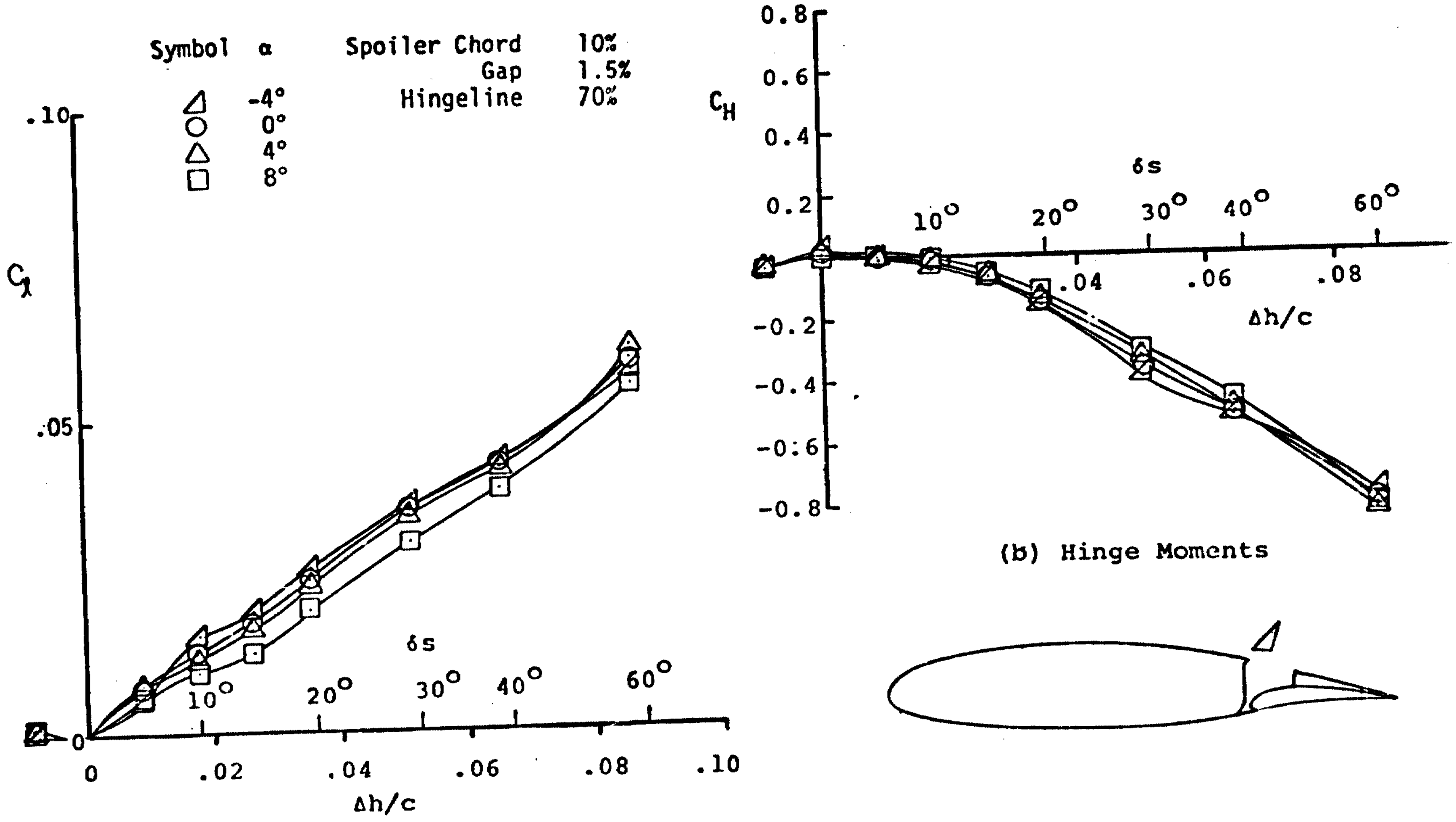


Figure 5. Redhawk Roll Time Histories



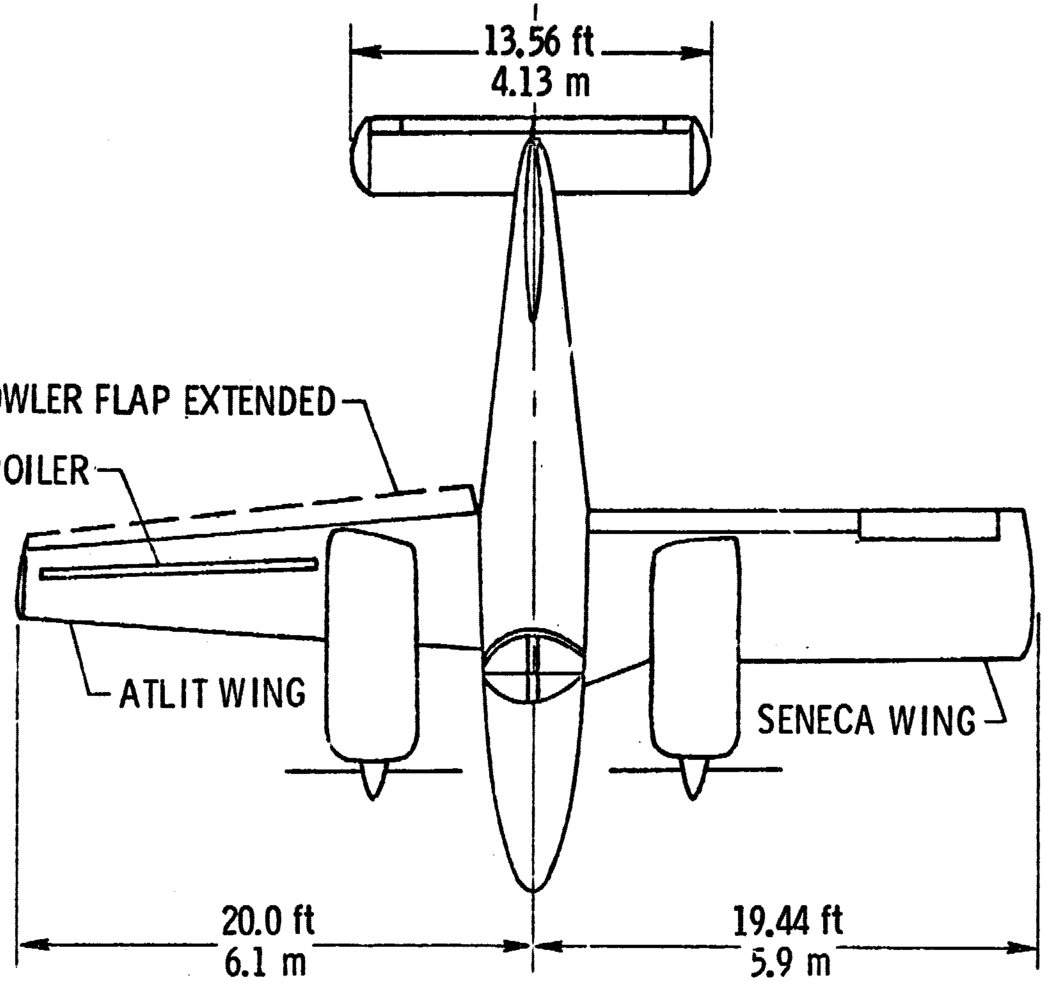
Design Chart of Spoiler Effectiveness

Figure 6



(a) Rolling Moments

Figure 7. Reflection Plane Tests of ATLIT Wing, $\delta_f = 0^o$



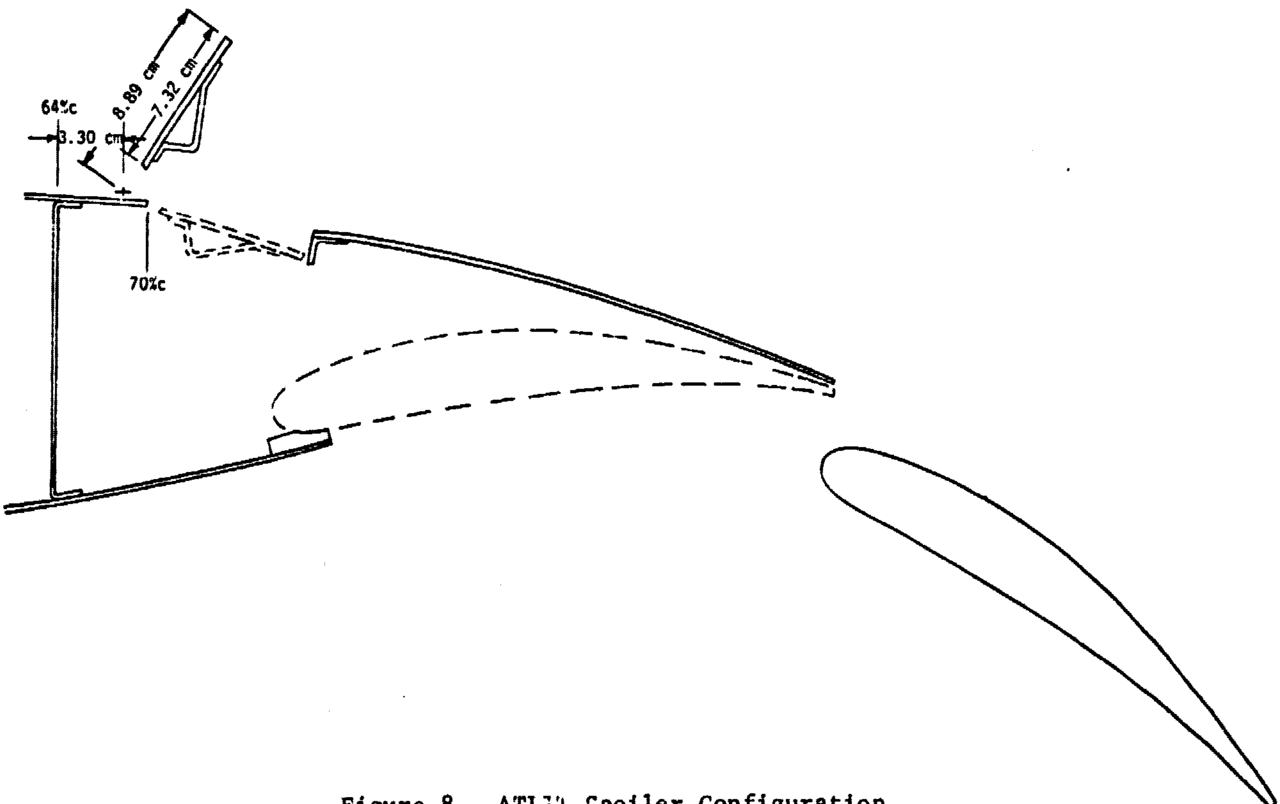


Figure 8. ATLIT Spoiler Configuration

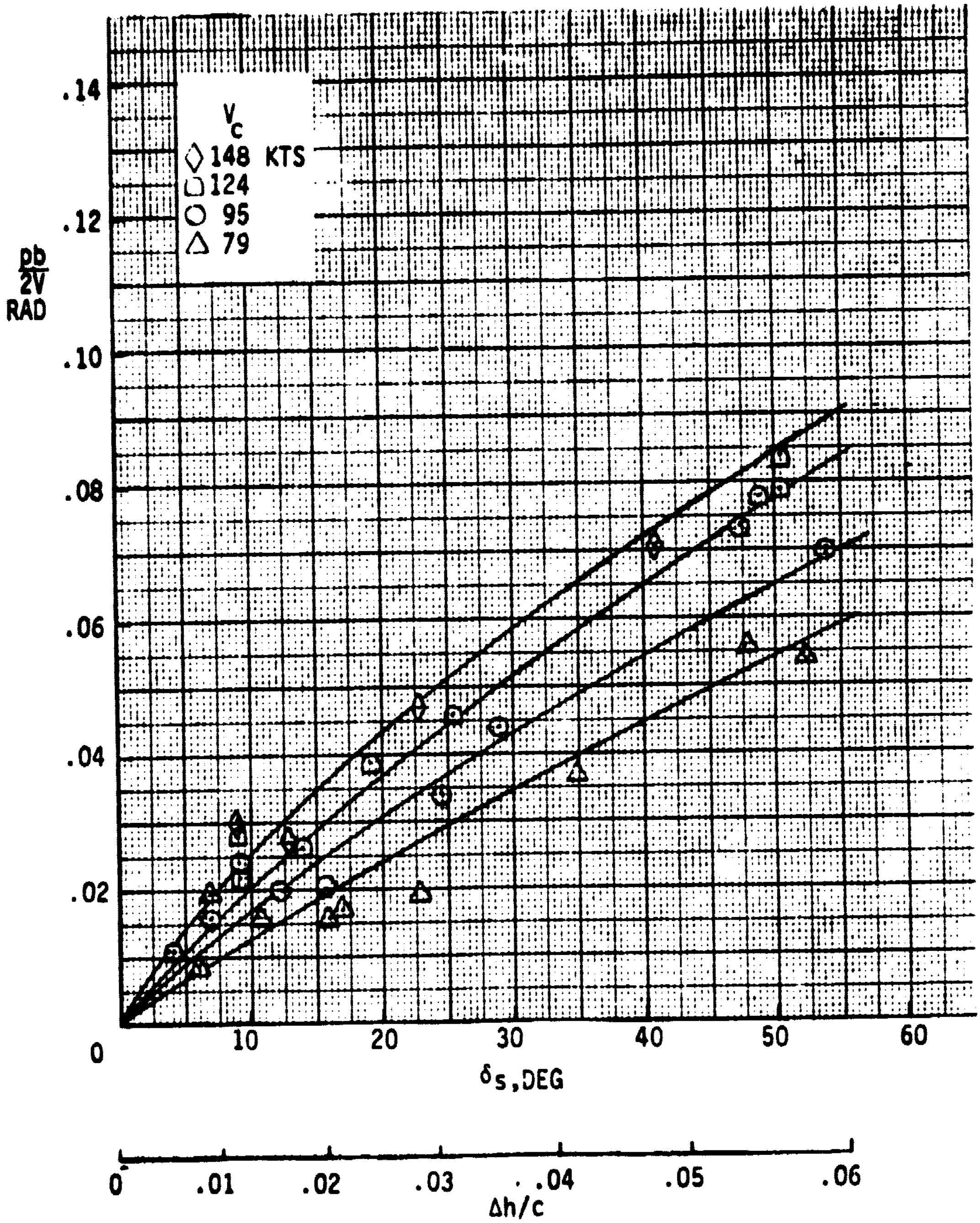


Figure 9. ATLIT Flight Test Roll Performance, $\delta_f = 0^{\circ}$

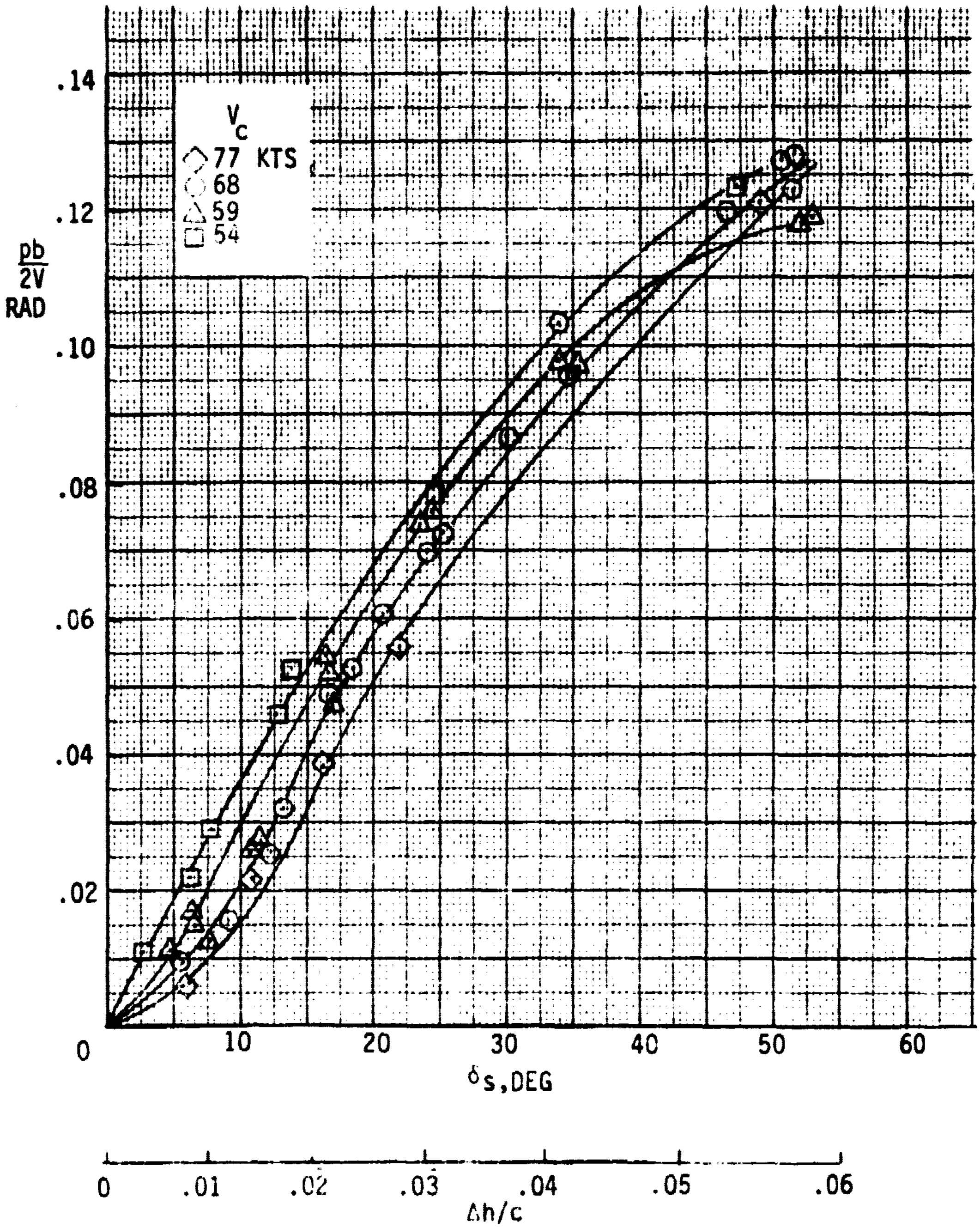


Figure 10. ATLIT Flight Test Roll Performance, $\delta_f = 30^o$

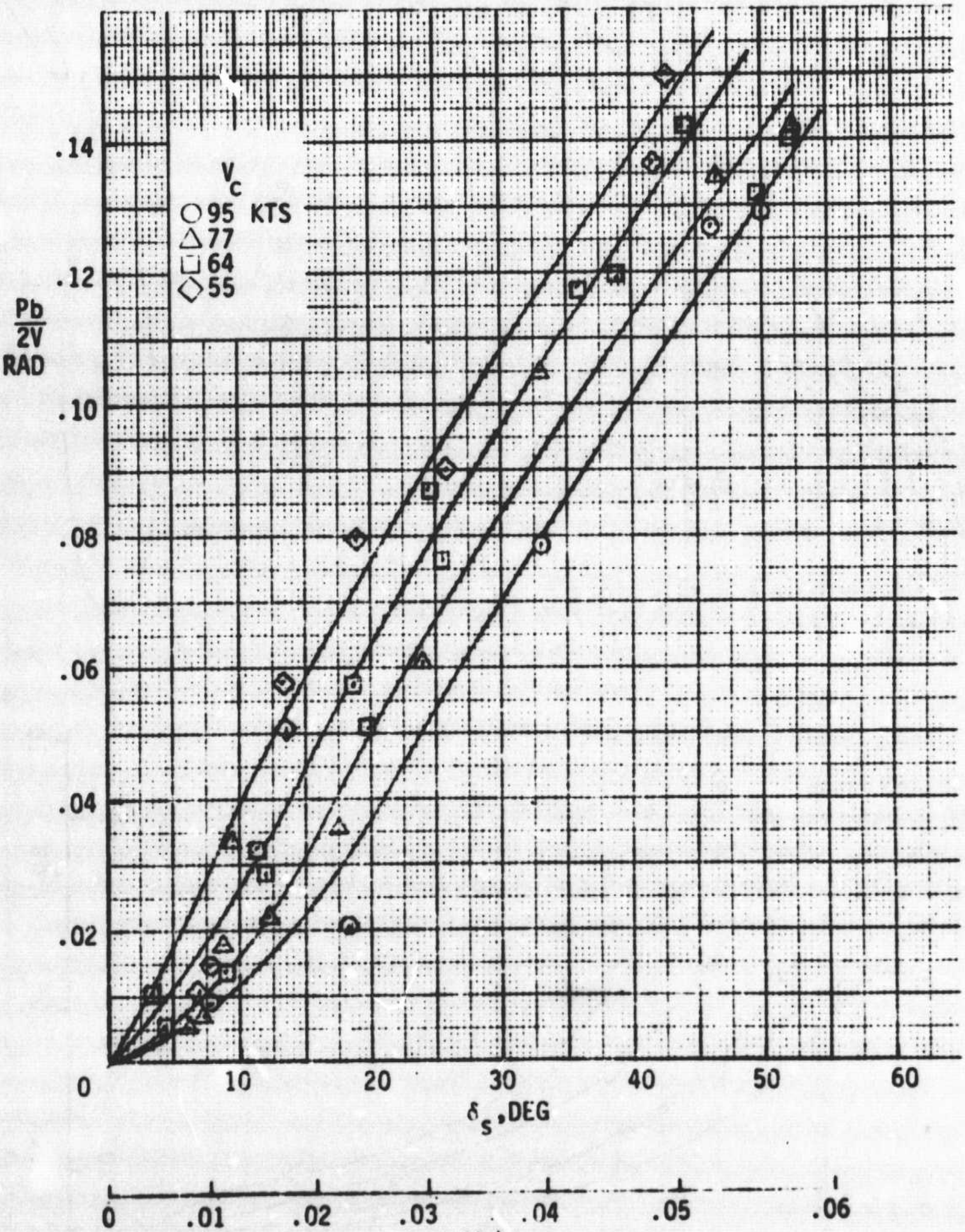
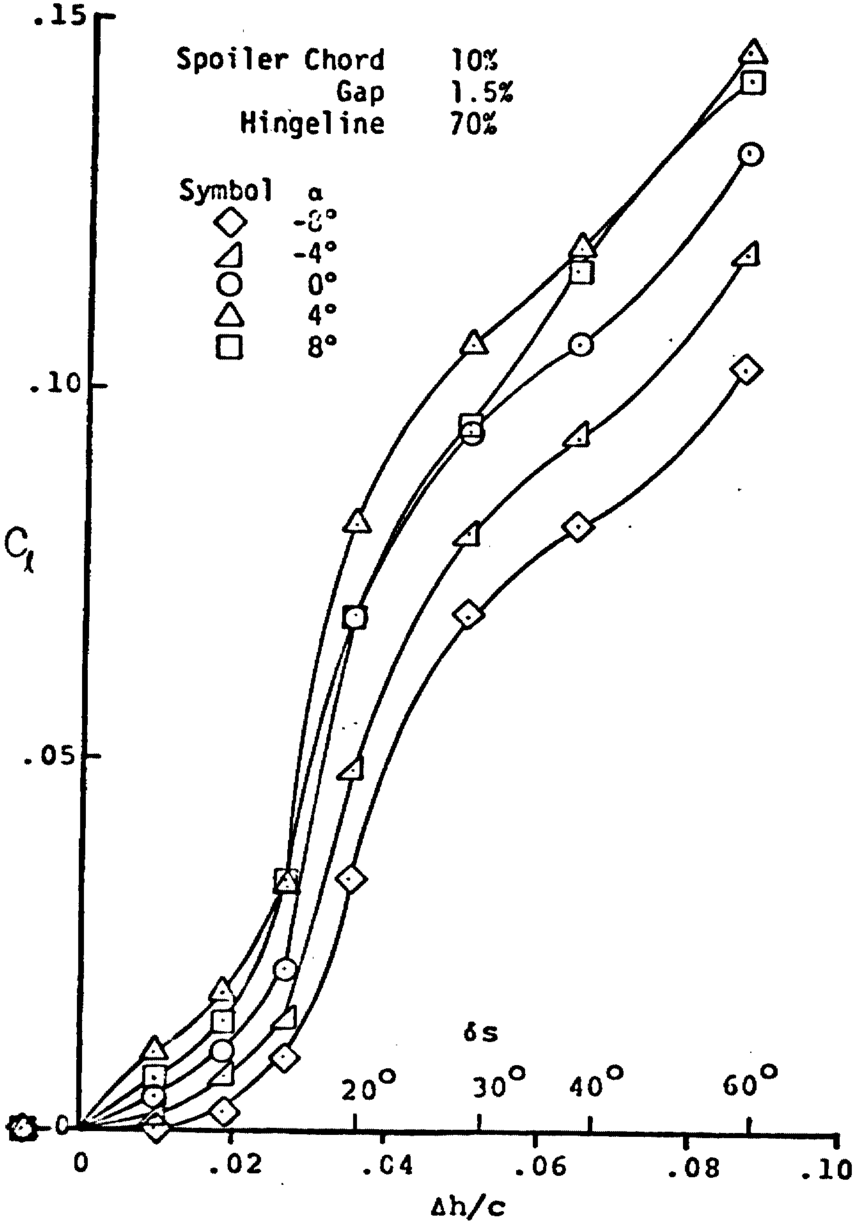
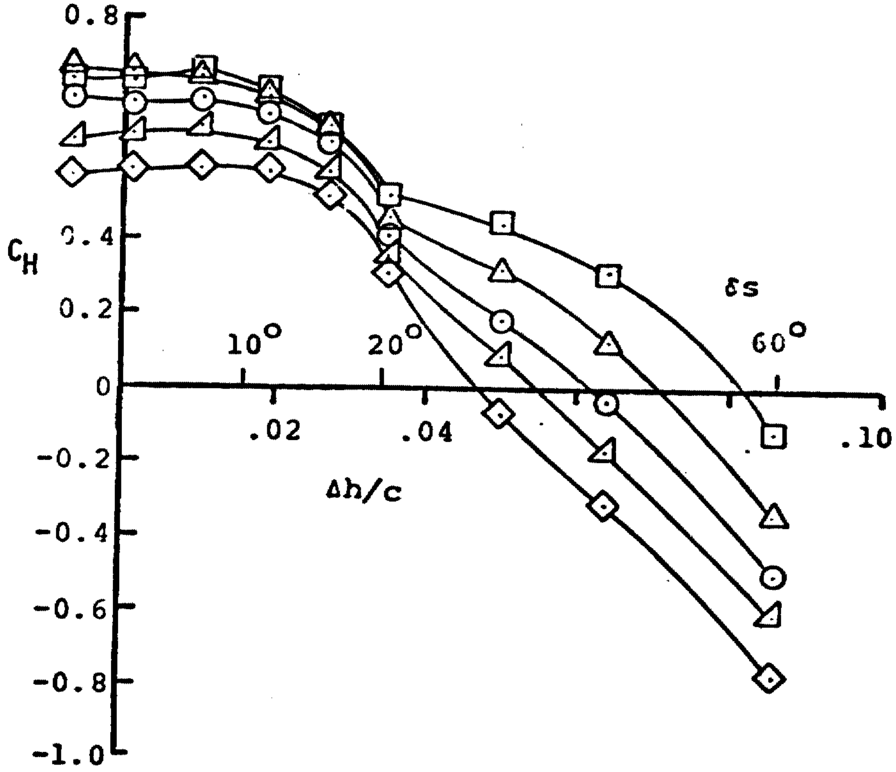


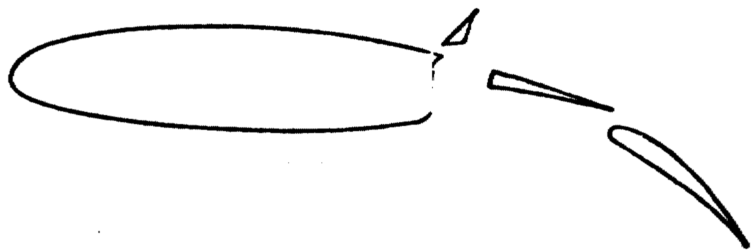
Figure 11. ATLIT Flight Test Roll Performance, $\delta_f = 37^o$



(a) Rolling Moments



(b) Hinge Moments



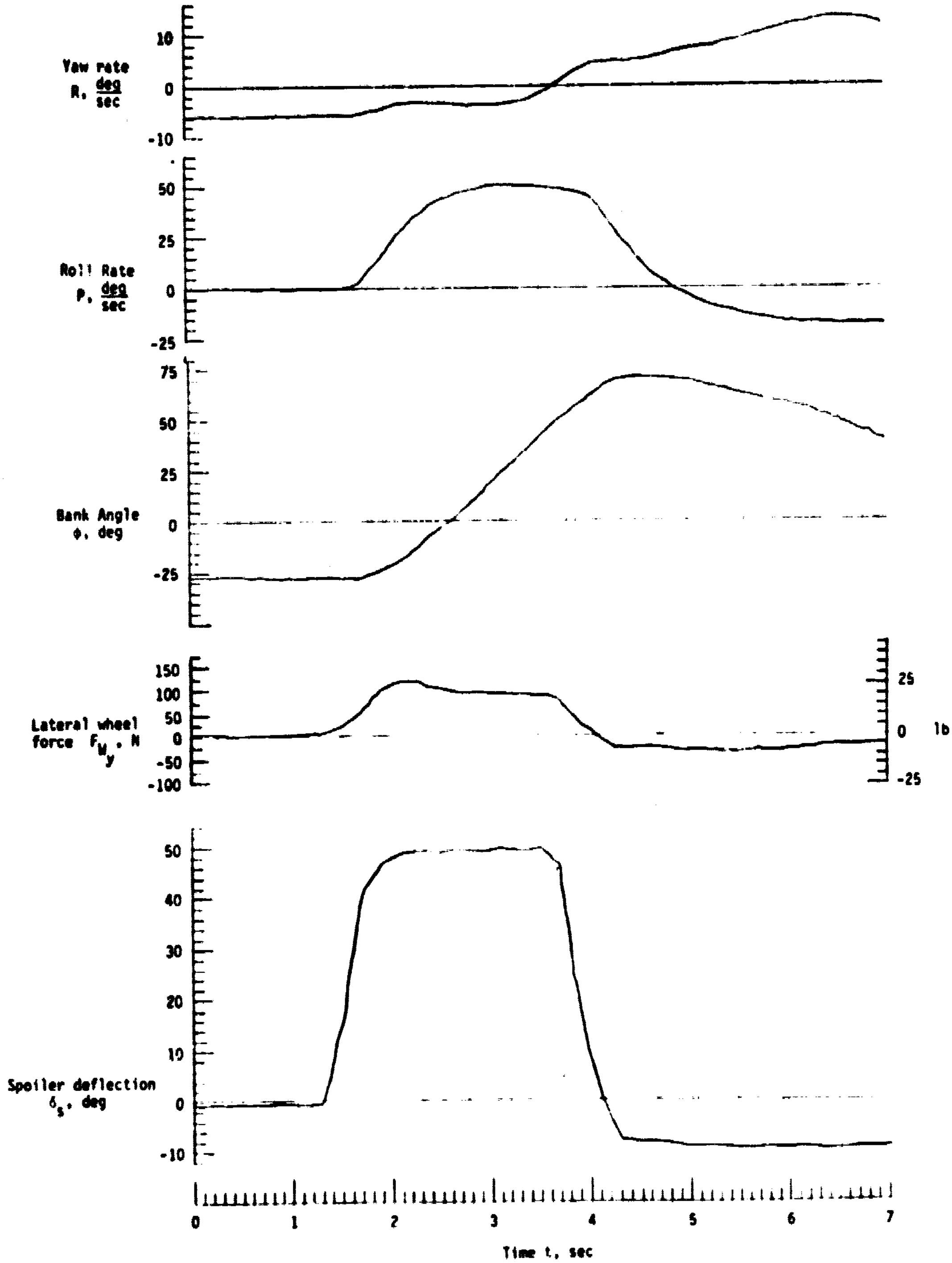


Figure 13. ATLIT Roll Time History, V_c = 78 kt, δ_f = 30°

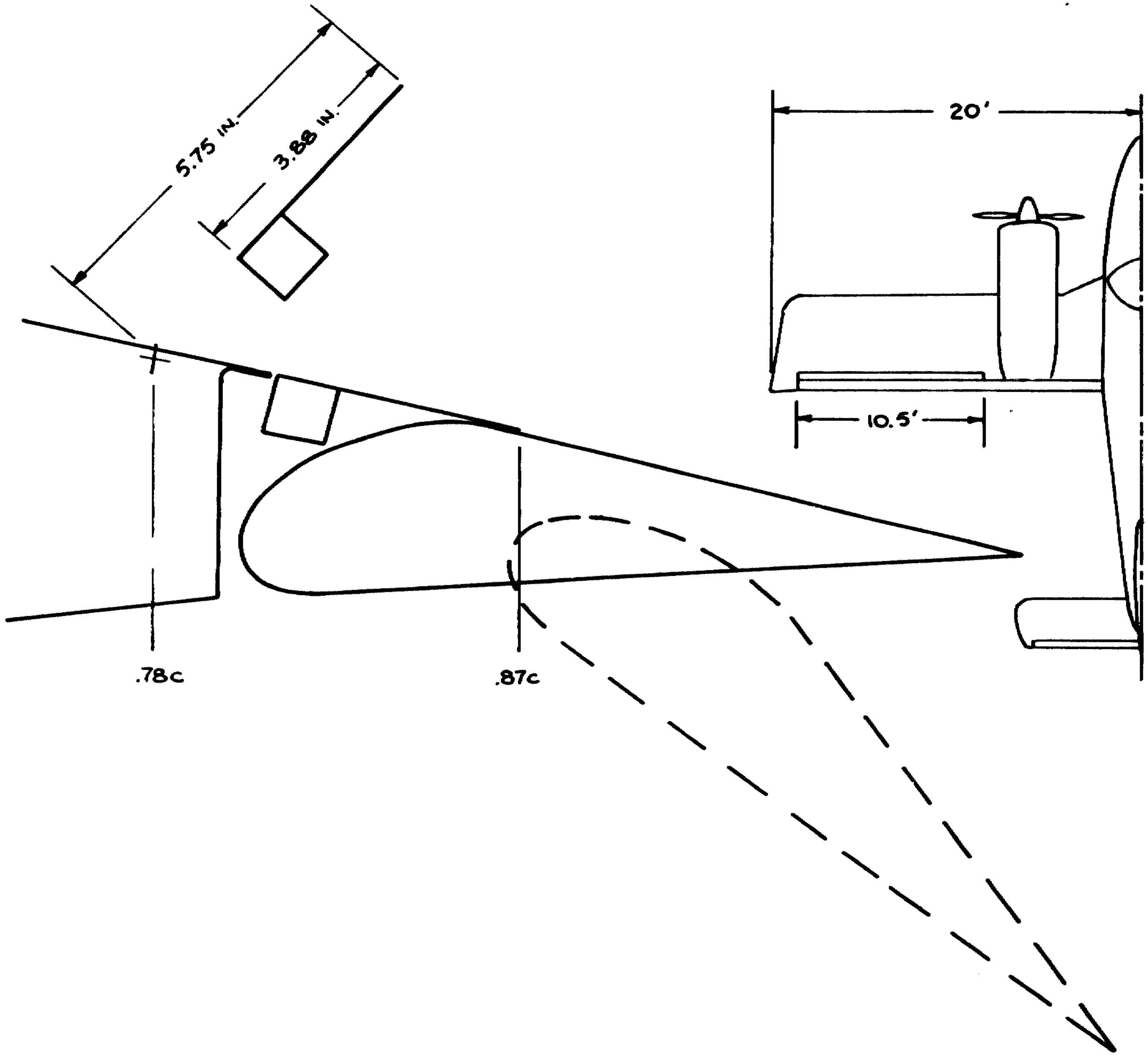


Figure 14. Robertson-Seneca Spoiler Installation

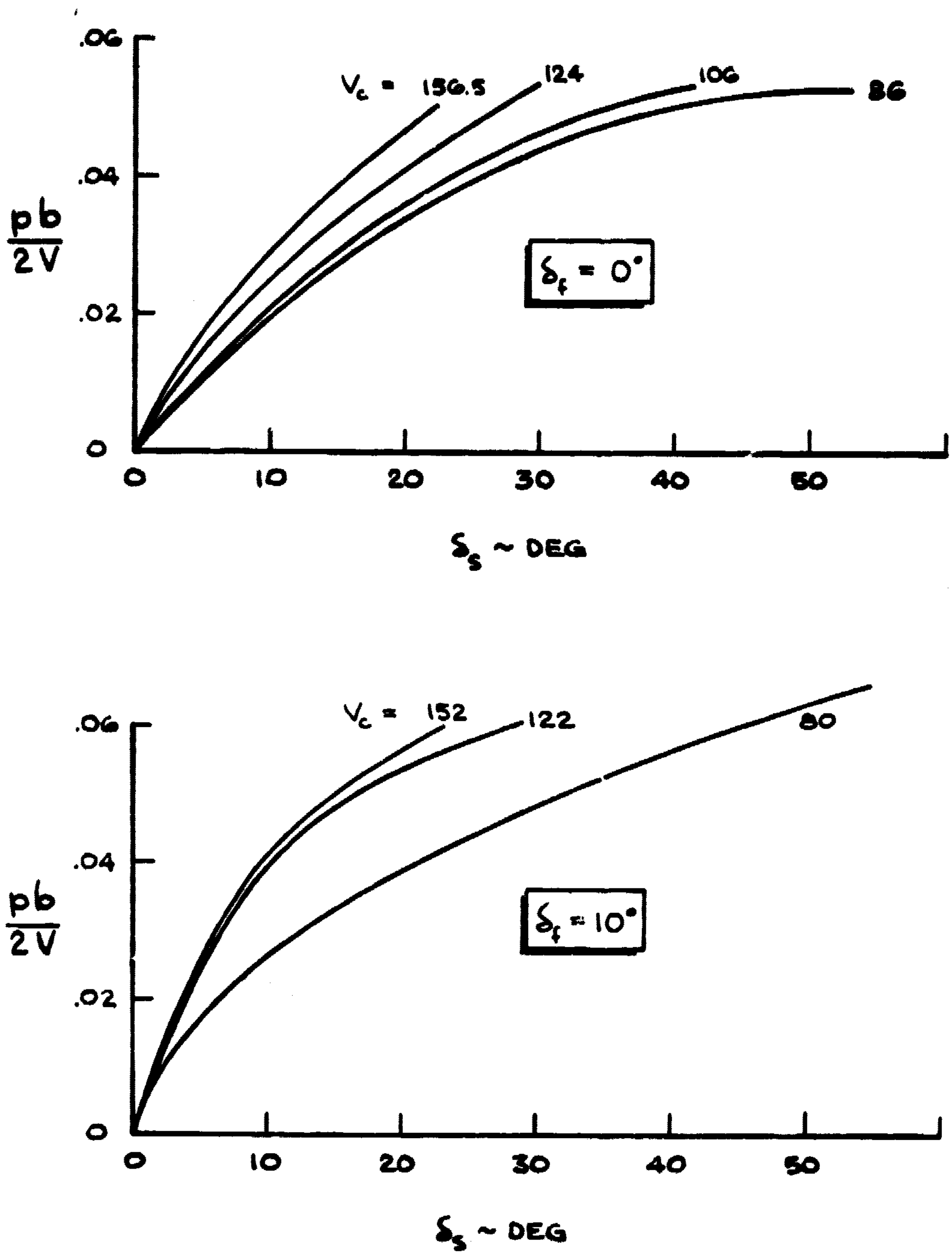


Figure 15. Roll Performance of the Robertson-Seneca, $\delta_f = 0^o$ and 10^o

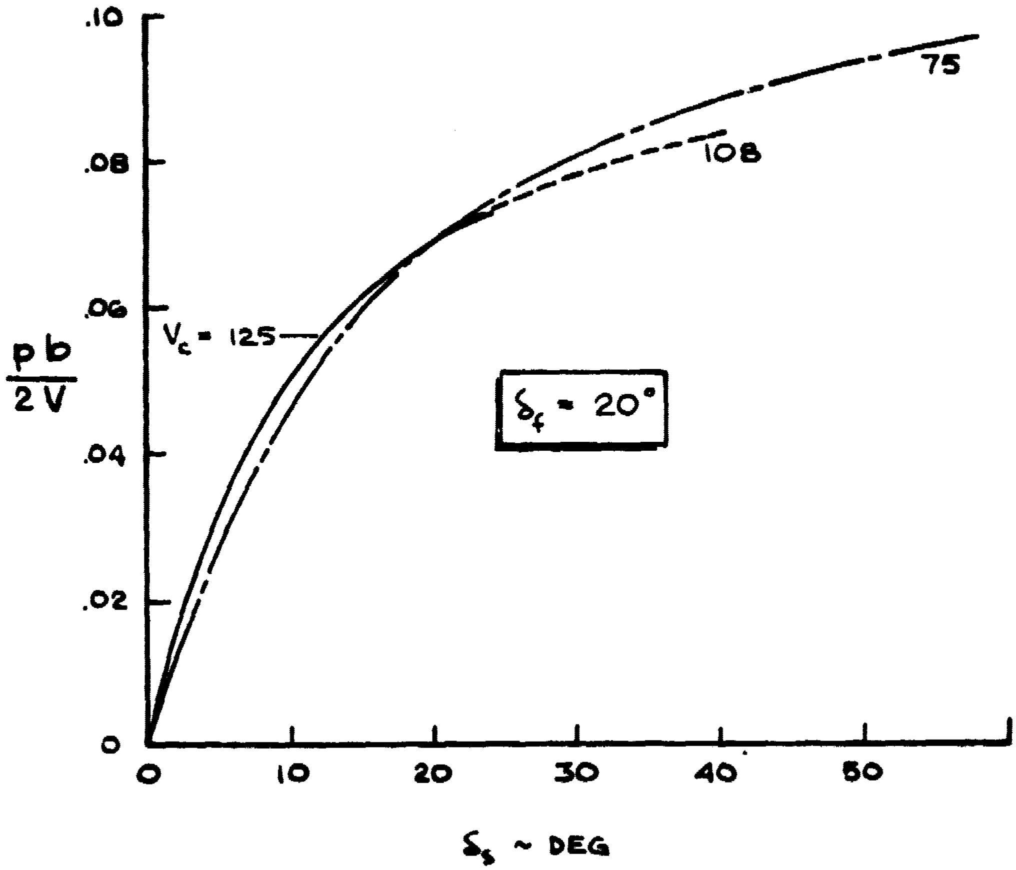


Figure 16. Roll Performance of the Robertson-Seneca, $\delta_f = 20^\circ$

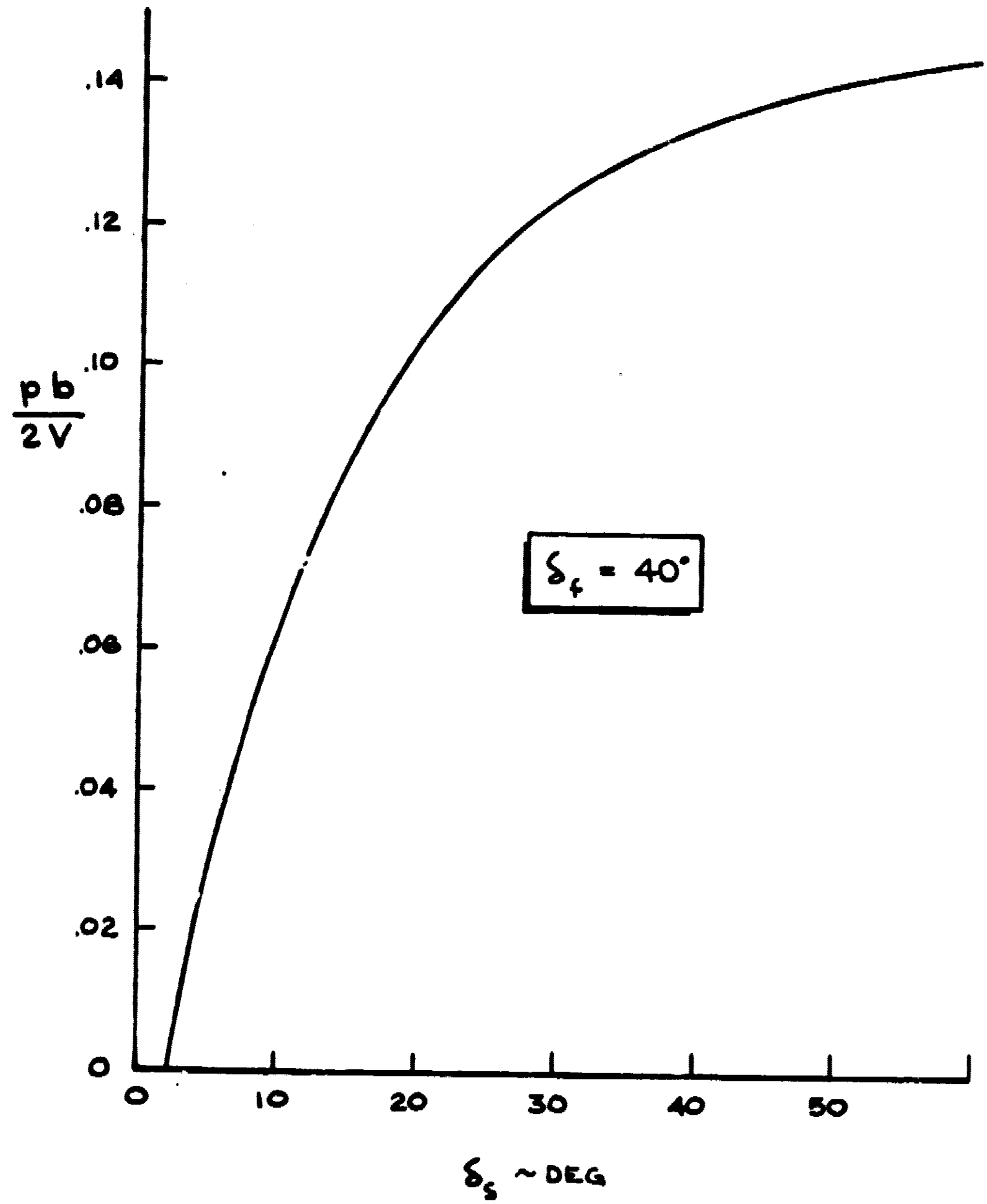


Figure 17. Roll Performance of the Robertson-Seneca, $\delta_f = 40^\circ$

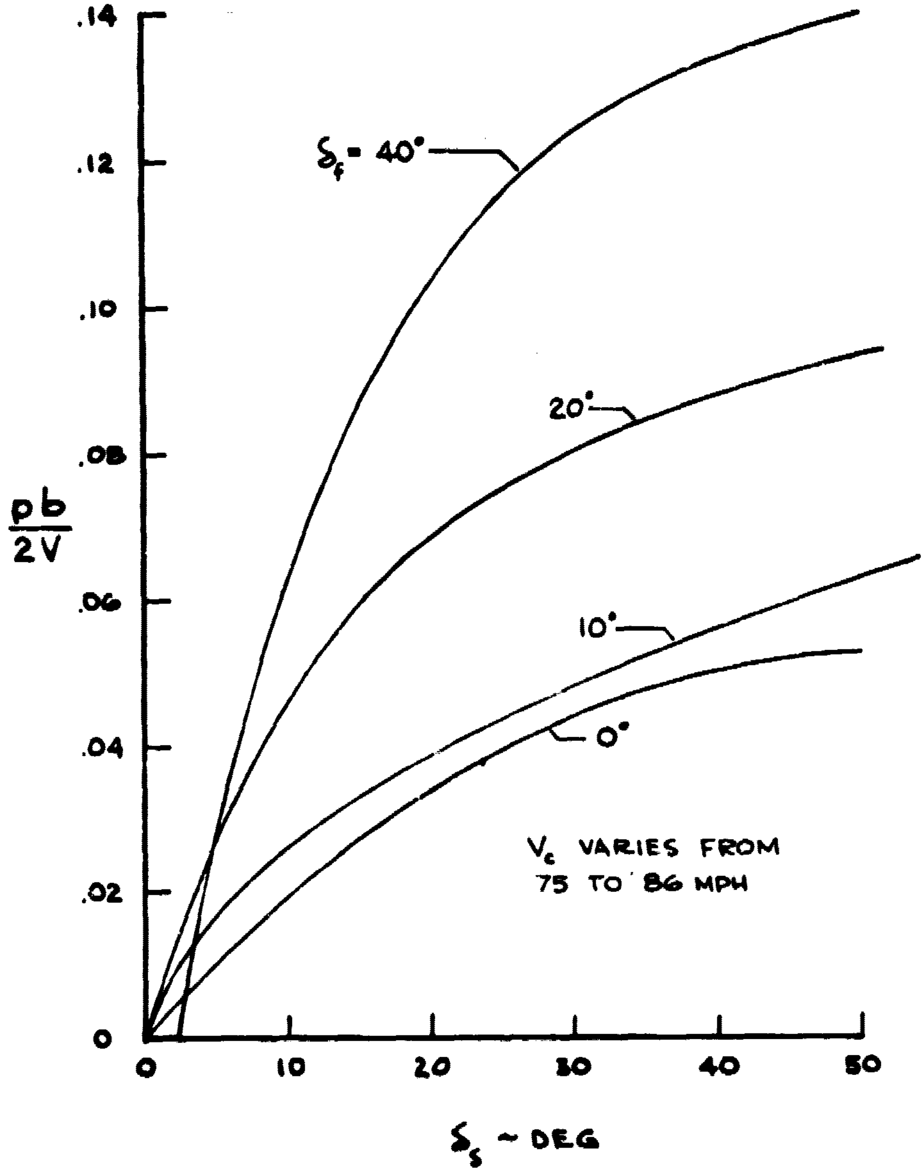


Figure 18. Effect of Flap Setting on the Roll Performance of the Robertson-Seneca

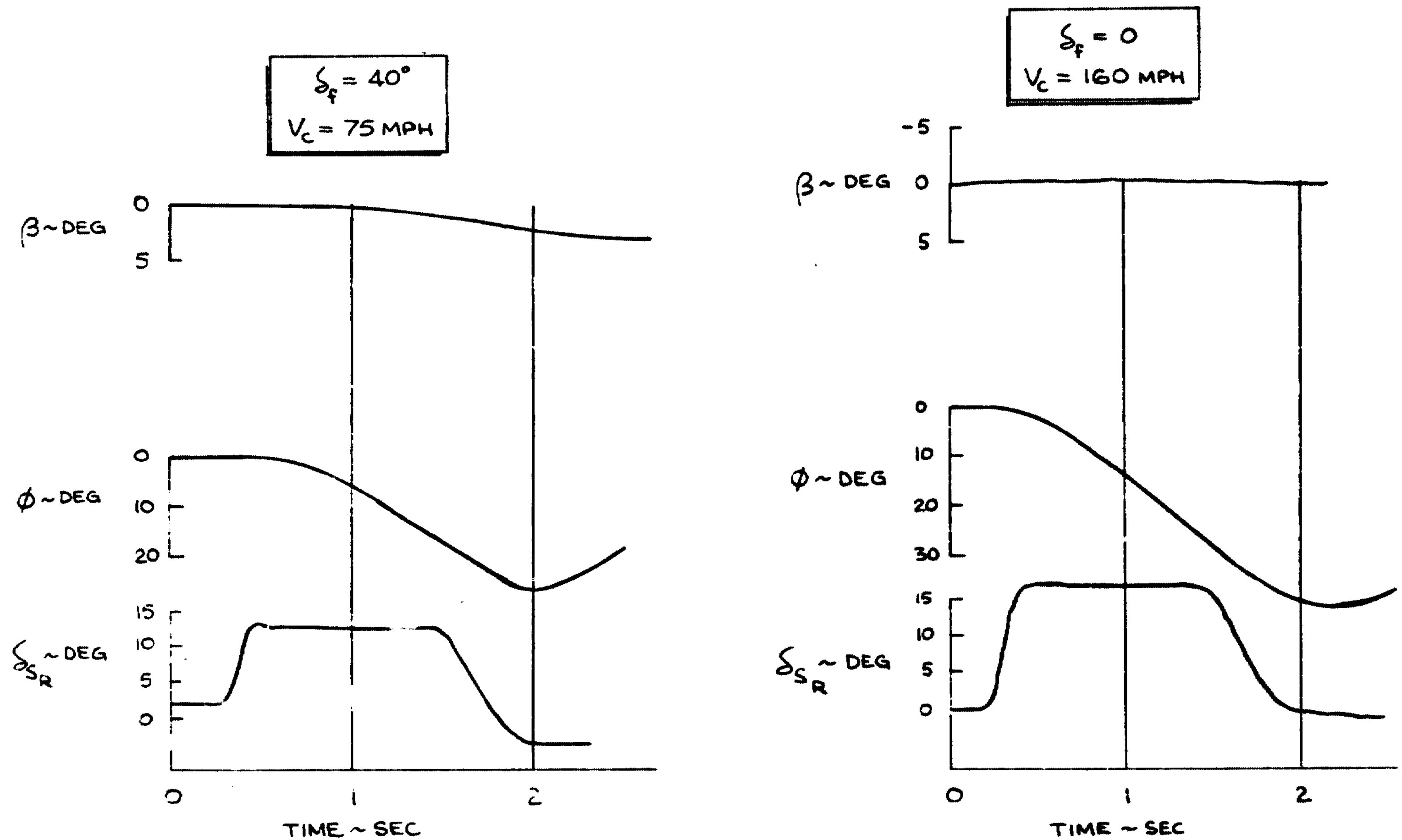


Figure 19. Time History of Roll Maneuvers of the Robertson-Seneca