NAVAL POSTGRADUATE SCHOOL
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THESIS

FEASIBILITY STUDY FOR
ENHANCED LATERAL CONTROL
OF THE P-3C AIRCRAFT

by

Kimberly Kay Smith

March 1989

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New mission requirements dictate the need to improve the P-3's defensive maneuvering capabilities. Research was conducted to find viable methods of increasing the current roll response of the P-3. First, a flight simulator was utilized to determine an initial "target" roll response. Next, a computer code was used to evaluate the aerodynamic effect of varying the size and deflection of the aileron. These results, along with the flight simulator tests, were used to analyze the requirements to reach the target response. Several ways to achieve this goal are discussed. It was found that by increasing the aileron deflection from $\pm 20^{\circ}$ to $\pm 25^{\circ}$ and increasing the aileron chord by 50%, a 58% increase in C_l could be realized. This does not reach the goal of a 100% increase in C_l, but, it does yield a large increase in lateral control response. An increase in aileron size and deflection along with some of the other suggested modifications would certainly approach the desired goal.

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Feasibility Study for
Enhanced Lateral Control
of the P-3C Aircraft

by

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requirements for the degree of

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ABSTRACT

New mission requirements dictate the need to improve the P-3's defensive maneuvering capabilities. Research was conducted to find viable methods of increasing the current roll response of the P-3. First, a flight simulator was utilized to determine an initial "target" roll response. Next, a computer code was used to evaluate the aerodynamic effect of varying the size and deflection of the aileron. These results, along with the flight simulator tests, were used to analyze the requirements to reach the target response. Several ways to achieve this goal are discussed. It was found that by increasing the aileron deflection from ±20° to ±25° and increasing the aileron chord by 50%, a 58% increase in C_l could be realized. This does not reach the goal of a 100% increase in C_l, but, it does yield a large increase in lateral control response. An increase in aileron size and deflection along with some of the other suggested modifications would certainly approach the desired goal.

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I. INTRODUCTION

A. BACKGROUND

The P-3 Orion aircraft has been successfully operated in the fleet since 1962. However, new mission requirements dictate the need to improve the defensive maneuvering capabilities of the aircraft. The Navy is currently investigating several ways to accomplish this goal.

As part of this investigation, Patrol Squadron Thirty-One (VP-31) at the Naval Air Station (NAS) Moffett Field, CA. has initiated a study into the feasibility of increasing the current roll response characteristics of the P-3C aircraft. Due to the age of the airplane, any potential modifications must be relatively inexpensive to incorporate. Additionally, the resulting improvements must justify the complexities required for the design changes and outweigh any penalties arising from these modifications.

The general consensus has been that there are no reasonable modifications that would provide the desired improvements at a justifiable cost. However, before making a final decision concerning potential modifications, VP-31 wanted to closely examine possible solutions to the problem. The squadron contacted the United States Naval Postgraduate School (USNPGS) to provide assistance in this study.

B. PURPOSE

The purpose of this thesis was to provide assistance to VP-31 in their efforts to enhance the defensive maneuvering capability of the P-3 aircraft. Research was conducted to determine viable methods of increasing the current roll response characteristics of the P-3C aircraft. Each of these methods was evaluated to predict the likely improvements that could be realized. Due to the reasons stated above, several obviously complex and expensive solutions, such as computer operated systems and deflected engine thrust, were not evaluated. However, once these options were disregarded, complexity and expense were no longer considered to be factors during this study.

C. DESCRIPTION OF THE P-3C AIRCRAFT

The P-3C aircraft is flown by the Navy in primarily the Patrol and Anti-Submarine Warfare (ASW) missions. Figures 1 and 2 show the P-3C aircraft and a dimensional wing drawing, respectively. The aircraft has four turboprop engines mounted on a low wing with a maximum recommended take-off gross weight of 135,000 lbs. The P-3 is equipped with a conventional, hydraulically boosted flight control system. An Automatic Flight Control System (AFCS) may be utilized to control and stabilize the aircraft in all three axes (pitch, roll and yaw) during long transits or low altitude maneuvering.

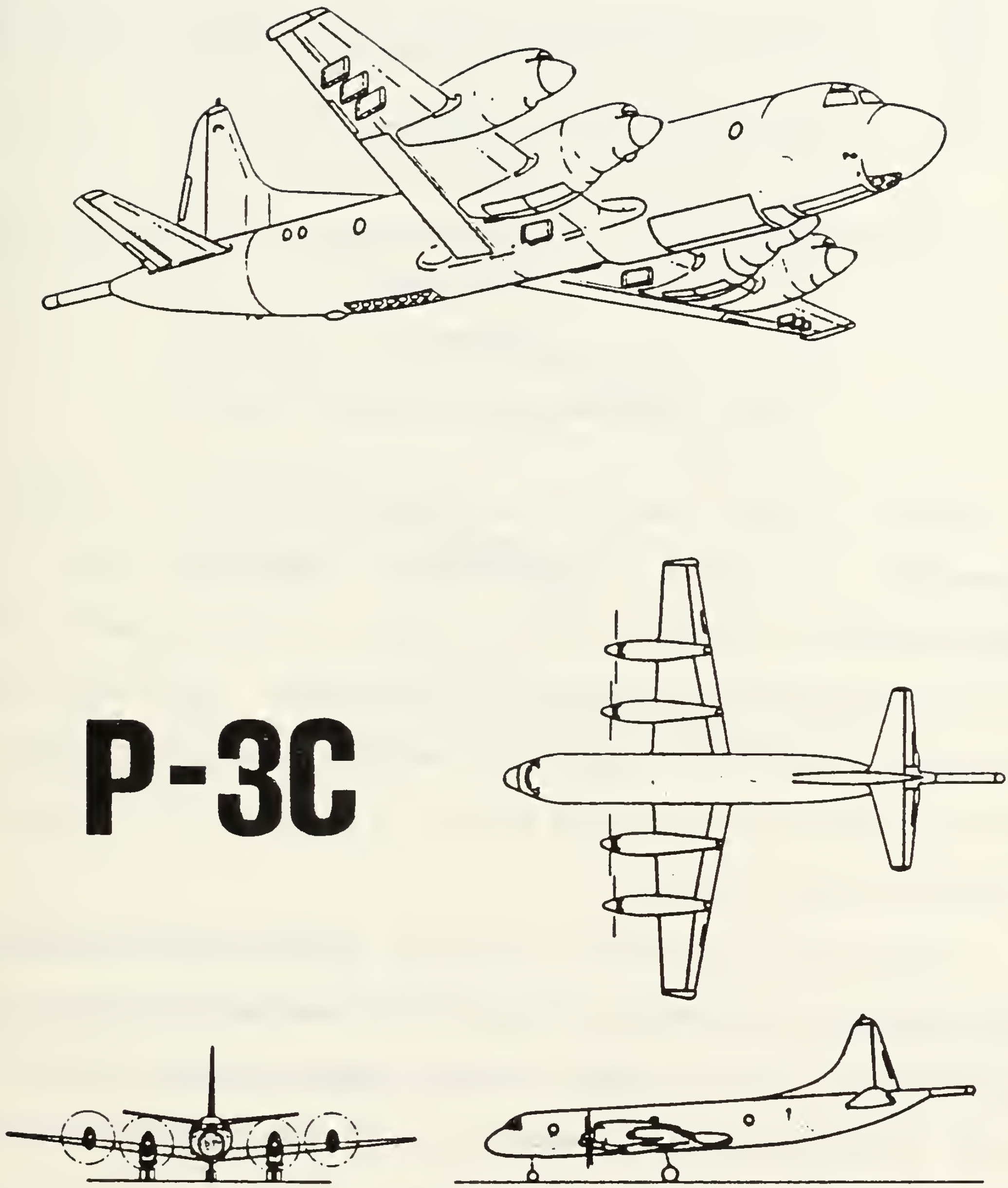

Figure 1

P-3C Aircraft

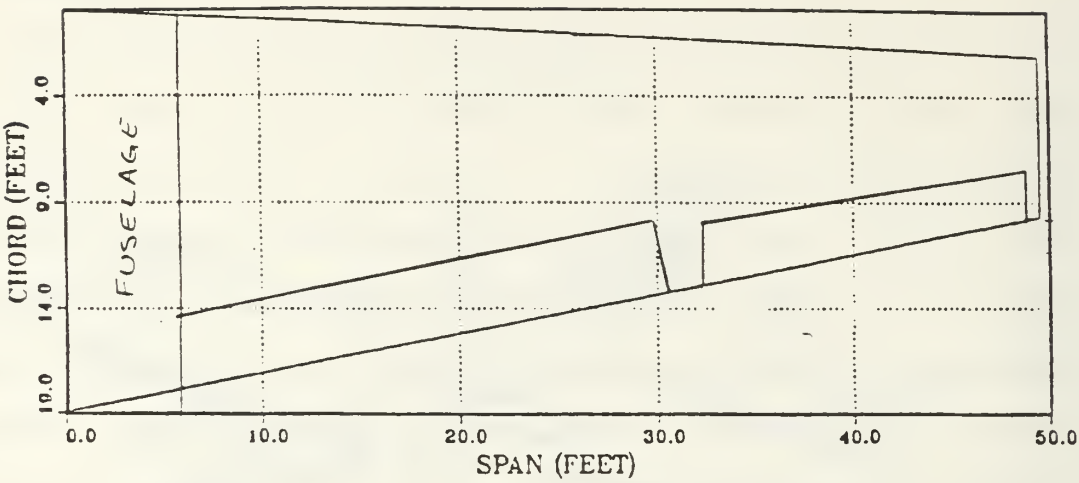

Figure 2

Wing Planform of the P-3C Aircraft

Each of the control surfaces (aileron, rudder and elevator) includes mechanically operated trim tabs. Additionally, high-lift Fowler flaps (illustrated in Figure 3) are incorporated inboard on the wings. The wing consists of symmetrical NACA airfoils. At the root is the NACA 0014 airfoil; the wing sections narrow, linearly, to the NACA 0012 airfoil at the wingtip.

The current operating envelope of the aircraft prohibits bank angles in excess of 65° for roll maneuvering and 70° for coordinated turns. Additionally, the airframe is limited to load factors between a negative 1 G and positive 3 G's for most operational gross weights.

A complete description of the P-3C aircraft and operating limitations can be found in Ref. 1. Detailed descriptions of the P-3 flight control system and wing flaps can be found in Refs. 2, 3 and 4.

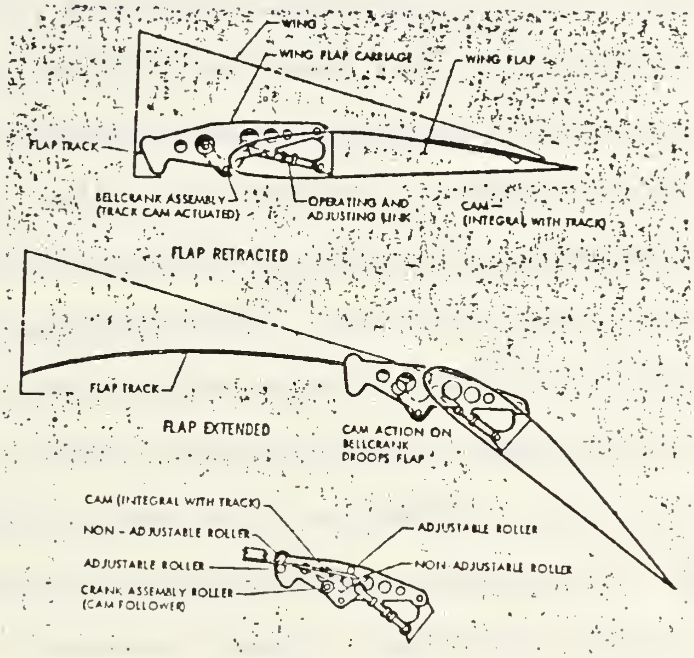

Figure 3
High-Lift Fowler Flap
Installation of the P-3C Aircraft
(From Ref. 3)

D. METHOD OF EVALUATION

Initial research identified several methods for increasing the lateral control response of an airplane. A select group of these methods was chosen for further investigation. As a first step in this investigation, it was necessary to determine an initial goal for the roll response improvement.

A flight simulator was utilized to qualitatively determine this "target" roll response increase and to quantify the resulting lateral characteristics. After the initial "target" response was determined, a computer airfoil code was used to evaluate the aerodynamic effect of airfoil sections with various sizes and deflections of the trailing edge control surfaces. These airfoil sections were then mathematically combined to determine the rolling moment coefficients for a variety of wing configurations. These results, in conjunction with the flight simulator tests, were used to analyze the modifications required to reach the desired lateral response.

Throughout this evaluation, several factors were not investigated, even though they are obviously important in the consideration of increased lateral response. The primary factor that was neglected was structural integrity. Neither the structural impact of any modifications to be made to the aircraft, nor the effect of the increased structural loads on the airframe due to the more aggressive maneuvering, were evaluated. Other less critical factors that were not considered will be discussed as appropriate.

II. PRELIMINARY RESEARCH

Literature research was conducted to determine what modifications, if any, had been made to other transport type aircraft to increase its roll rate or roll acceleration. Additionally, current technology design standards were investigated to discover the options available in the area of lateral control response.

Research revealed no historical data on increasing the roll response of a transport type aircraft. There were, however, two reports on increasing the lateral response characteristics of fighter type aircraft. Although the mission for fighter aircraft is much different than that for the P-3, the modifications and results proved to be very informative. These reports will be discussed as well as the results from some previous P-3 flight tests. Finally, The impact of these reports on the P-3 study will also be discussed.

A. F/A-18A AIRPLANE WITH ROLL RATE IMPROVEMENTS INCORPORATED

Reference 5 discusses tests conducted by the Navy at the Naval Air Test Center (NATC), to evaluate the roll rate improvements incorporated in the F/A-18A Aircraft. According to the findings of the report, the F/A-18A aircraft had exhibited serious problems with inadequate roll performance. McDonnell Aircraft Company incorporated several major hardware changes to improve the lateral performance characteristics of the aircraft. These changes included:

1. An increase in aileron size by extending the aileron surface to the wingtip.

2. Modifications to the wing structure designed to increase the wing stiffness.

3. Trailing edge flaps were moved aft 1.5 in. at zero deflection to allow for increased flap range from 8° trailing edge up (TEU) to 45° trailing edge down (TED). These values were previously 0° TEU to 45° TED. This change allows for ±16° of differential trailing edge flaps during rolls.

4. An increase in differential tail deflection authority from ±20° to ±26°.

5. In addition to the hardware changes, many software modifications were necessitated by the various roll rate improvements. These changes will not be discussed since they are not applicable to the P-3.

The test results showed that the maximum steady state roll rates and time-to-bank to 90° were significantly improved throughout most of the flight envelope that was investigated. However, the resulting characteristics were still not adequate for the requirements of the present day fighter aircraft.

B. F-4S AIRPLANE LATERAL/DIRECTIONAL FLIGHT CONTROL SYSTEM MODIFICATION

Reference 6 discusses tests conducted by NATC to evaluate the modifications to the lateral/directional flight control system (Roll Mod) of the F-4S aircraft. According to this report, the F-4S exhibited sluggish lateral characteristics in the power approach (PA) configuration due to the installation of leading edge slats. Several modifications were incorporated into the roll and yaw axes of the AFCS. These changes included:

1. Addition of a roll rate gyro feedback signal to the rudder series servo.

2. Reduction of the yaw rate gyro feedback signal to the rudder series servo.

3. Addition of a roll stick gain to lateral series servo.

The tests results indicated that the incorporation of the Roll Mod in the F-4S airplane improved lateral control.

C. PREVIOUS TESTS CONDUCTED ON THE P-3 AIRCRAFT

1. Removal of the Aileron/Rudder Interconnect from the P-3B/C Aircraft

Reference 7 discusses tests conducted by NATC to determine the effect of removing the aileron/rudder interconnect (ARI) from the P-3 aircraft. The following is a summary of this report.

An ARI is included as part of the lateral control system of the P-3 aircraft. The primary purpose of the ARI is to improve aileron control wheel centering and to reduce the rudder force required in shallow turns by means of a spring in an interconnection cartridge. Because of numerous instances of aileron/rudder control binding and jamming associated with the ARI, the Navy was considering removing the ARI.

An evaluation of the P-3 was conducted to determine if the removal of the ARI resulted in a change to the lateral flying qualities. According to the report, none of the four test pilots involved in the testing was able to perceive a change in the lateral-directional flying qualities throughout the qualitative phase of tests. It was concluded that the removal of the ARI had no significant effect on the lateral control effectiveness of the P-3 airplane during mission tasks.

2. P-3 Flight Simulators

Reference 8 discusses previous testing conducted to verify the flight fidelity characteristics of the P-3 Flight Simulators that were used for this investigation. This report was used extensively for comparison between the original data and results from this evaluation and will be discussed as appropriate. The report includes both simulator and actual aircraft test data.

D. ANALYSIS OF RESEARCH

Several of the modifications that were made to the fighter aircraft could certainly be considered for the P-3, particularly in the area of aileron sizing and flight control modifications. The modifications were not sufficient enough to create a tactical fighter. However, the desired purpose for the P-3 lateral response improvements is to enhance the defensive maneuvering capabilities of the aircraft. Although the idea of taking advantage of the ARI initially appeared to be a plausible option, the previous tests show that this is not the case.

There are several other options to increase the lateral response in addition to those previously discussed. Those that were evaluated will be discussed as appropriate. Some methods that were not evaluated but appear viable include the addition of stall fences and spoilers. Although no background information has been found, it was learned from a retired Navy pilot that the addition of stall fences produced a significant improvement in the lateral response of the S-2 aircraft several years ago.

Spoilers have been tried and proven as roll generating devices. Although spoilers were not evaluated directly, the results encountered during rolling moment coefficient tests (discussed later) can be applied to spoilers as well as to other lateral control surfaces. As with ailerons, spoilers increase the rolling moment of the wing. It is recommended that further evaluation be conducted to determine the effect of both stall fences and spoilers.

III. FLIGHT SIMULATOR TESTS

A significant increase in roll rate and acceleration is desired for defensive maneuvering. However, more sensitive lateral control can lead to the degradation of many of the other mission requirements of the P-3. Anticipated problems include an increase in the workload as well as a decrease in the accuracy while performing the precise heading and lineup changes required during approaches and operational ASW maneuvers.

Two P-3 flight simulators were utilized to provide a quantitative investigation of various changes which might increase the lateral response of the aircraft. Throughout the tests, all changes were qualitatively evaluated with respect to aircraft response and pilot workload. This investigation permitted determination of an initial "target" roll response, representing a realistic compromise between the increased roll rate and the resulting higher pilot workload. The changes to be investigated were simulated by modifying various portions of the simulator software. These software modifications will be described as they are discussed in the report. During the tests, software modifications were incorporated by the flight lead engineer of the Link Tactical Military Simulation Corp. Only one modification was evaluated at a time to determine the effect of each individual change. Obviously, a combination of these changes could be used to create larger rolling moments.

Nine hours of tests were conducted during two separate simulator periods. Two Navy P-3 pilots performed different mission maneuvers and test inputs for each of the lateral axis changes.

A. DESCRIPTION OF TEST EQUIPMENT

1. Operational Flight Trainers (OFT)

The simulators used were Device 2F87(F) OFT Nos. two and three, operated by COMPATWINGSPAC at NAS Moffett Field, CA. Each of the OFT's incorporates a P-3C flight compartment facsimile, mounted on a six-degree-of-freedom motion base. The flight compartment includes an instructor station, pilot and engineer stations, and additional seats for observers. The flight compartment arrangement is illustrated in Figure 4. A computer generated visual display system is mounted on the flight compartment and was used to provide the necessary visual cues to the pilots throughout testing. A detailed description of the OFT's can be found in Ref. 9.

2. Data Acquisition Equipment

The amount of time available to conduct the tests was limited because of the operational status of the flight simulators. This limitation restricted the scope of these tests and precluded elaborate instrumentation. Most of the data was obtained using hand-held stopwatches and was recorded

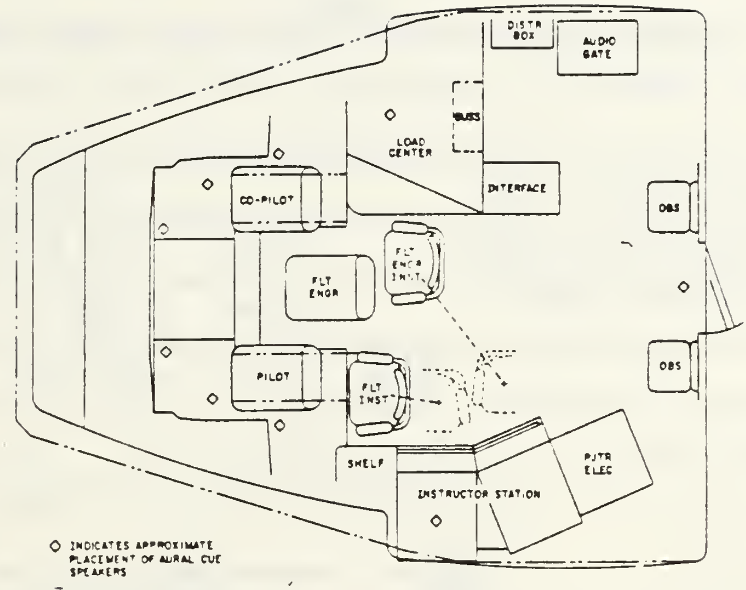

Figure 4
P-3C Operational Flight Trainer
Flight Compartment Arrangement
(From Ref. 9)

manually. Additionally, included as part of the instructor's station were two Cathode Ray Tubes (CRT's) which provided continually updated information about the instantaneous flight condition of the trainer. The flight conditions page proved to be especially helpful during steady state conditions. A sample copy is shown in Table I. Hard copies of this page were easily made, but required excessive time to print. Initially, several hard copies of each maneuver were printed to provide a rough time history. However, this procedure became too time consuming. Therefore, during the latter

TABLE I

SAMPLE COPY OF THE FLIGHT CONDITIONS PAGE

MALF THUMBWHEEL SETTINGS:	NAV/COMM		
B22 BARO ALTIMETER VIBRATOR	VHF-1	VOR 113.90	ICS 0
B22 BARO ALTIMETER VIBRATOR	VHF-2	TR 123.20	
MALFS PENDING (TIMED):	TACAN	TR 0123	IFF TRANSPONDER
	ADF	ADF 0764 S	
00:00			MASTER OFF
00:00	UHF-1	TRG 353.80	
00:00	UHF-2	OFF	MODE -1 03
			-3 0100
	HF-1	OFF	-4 OFF
TIMER 00:00:00 MET 00:02:12	HF-2	OFF	-C ON

FLIGHT CONDITIONS PAGE

FLIGHT TIMER	00:00:00	MET TIMER	00:02:13
	CONFIGURATION/CONDITIONS		
GROSS WEIGHT	88576	PRESSURE ALTITUDE	430.5
C.G.	24.80	CALIBRATED AIRSPD	209.6
FLAP POSITION	0.0	EQUIVALENT AIRSPD	209.53
GEAR POSITION	0.0	TRUE AIRSPD (F/S)	356.19
		MACH NUMBER	0.32
	FLIGHT/AERO		
PITCH ANGLE	0.8	BANK ANGLE	-0.5
ANGLE OF ATTACK	1.3	SIDESLIP	0.9
HEADING ANGLE	83.4	RATE OF CLIMB (FPM)	-194
PITCH VELOCITY (D/S)	0.055	PITCH ACCELERATION	-0.0388
ROLL VELOCITY (D/S)	0.625	ROLL ACCELERATION	0.0126
YAW VELOCITY (D/S)	-0.078	YAW ACCELERATION	-0.0036
NORTH-SOUTH VELOCITY	354.31	NORTH-SOUTH ACCEL	-1.336
EAST-WEST VELOCITY	-35.89	EAST-WEST ACCELERATION	-0.060
VERTICAL VELOCITY	2.94	VERTICAL ACCELERATION	-4.497
LONGITUDINAL ACCEL	-0.0229	TOTAL PITCHING MOMENT	-33983
LATERAL ACCEL	0.0019	TOTAL ROLLING MOMENT	10688
VERTICAL ACCEL (G'S)	-1.1516	TOTAL YAWING MOMENT	-6771
	CONTROL LOADING		
ELEVATOR POSITION	0.12	ELEVATOR TRIM TAB	7.05
COLUMN FORCE	0.44	COLUMN POSITION	6.17
RUDDER POSITION	0.40	RUDDER TRIM TAB	-0.18
PEDAL FORCE	0.00	PEDAL POSITION	0.04
AILERON POSITION	0.82	AILERON TRIM TAB	-0.59
WHEEL FORCE	5.58	WHEEL POSITION	3.84
	ENGINES		
TOTAL THRUST	2784	THRUST COEFFICIENT	0.01
THROTTLE ANGLE	47.4	LATERAL T.C.	0.02
ENGINE S.H.P.	712	ENGINE T.I.T.	562
	WEIGHT AND BALANCE		
IXX INERTIA (/ 1024)	817	IYY INERTIA (/ 1024)	855
IZZ INERTIA (/ 1024)	1645	CROSS PRODUCT/INERTIA	42910

NOTE: VALUES INVALID DURING ATG - TO USE COL MARKER SW FOR SNAPS SET COLSNP TRUE phases of the data collection, hard copies were printed for only the steady state condition maneuvers.

In addition to the flight compartment, the simulator hardware consists of digital computers, interface equipment and associated electronics equipment required to simulate the aircraft. As part of this equipment, there is an interactive computer which was used to make the software changes during the tests. This allowed for quick modifications with minimum stop time and significant flexibility throughout testing.

B. METHOD OF TEST

1. General Test Maneuvers

The roll response testing was conducted in accordance with procedures in the USNTPS Fixed Wing Stability and Control Flight Test Manual (Ref. 10). The roll rate and acceleration for each of the software changes, as well as a baseline condition (the unmodified simulator), were evaluated in two ways. First, the aircraft was established in a straight and level static flight condition. A full lateral step input was applied to the control yoke while maintaining altitude and power setting. A stopwatch was used to determine the elapsed time from 0° to 60° angle of bank. Although this does not correspond to a steady state roll rate, it does present a consistent quantitative method for comparison between the various simulated conditions. This maneuver was performed in both the left and right directions.

The next maneuver was initiated from a steady, level 60° angle of bank turn. A full lateral control step input was then applied, to the control yoke, in the opposite direction while maintaining altitude and power setting. A stopwatch was used to determine the elapsed time from 60° to 50°, and from 0° to 60° in the opposite direction. Although not a precise indicator of roll acceleration, the time to roll through the initial 10° does provide a consistent quantitative method for comparing roll acceleration between the different simulated conditions. It was found that the aircraft had reached a steady state roll rate when passing through 0° angle of bank. Therefore, the time to roll through the final 60° provided a relatively accurate value of the steady state roll rate. The flight conditions page was used to verify the computed steady state values. The tests and test conditions that were conducted are summarized in Appendix A, Table I. A tabulated summary of the results from the stopwatch measurements and flight conditions pages is shown in Appendix A, Table II.

Definitions of the maneuver descriptions and simulator conditions used throughout this report are shown in Tables II and III respectively. All tests were conducted at a gross weight of approximately 92,000 lb. with a CG of about 24.5% Mean Aerodynamic Chord (MAC). The landing gear and flaps were up except where required for approaches, landings and take-offs, as well as for the split-flap evaluation. Neither the flight conditions page, nor stop watch times, were obtained

TABLE II
MANEUVER DESCRIPTIONS

0 TO 60 and 60 TO 60	INDICATE ROLLS INITIATED FROM EITHER LEVEL FLIGHT OR A STEADY 60 DEG BANK IN THE RIGHT OR LEFT DIRECTIONS AS INDICATED (THROUGHOUT THE REPORT, VALUES LESS THAN 0 REPRESENT MANEUVERS TO THE LEFT)
HEADING CHANGES	QUALITATIVE EVALUATION OF PRECISE HEADING AND LINEUP CHANGES
APPROACH TAKE OFF LANDING	QUALITATIVE EVALUATION OF VARIOUS MISSION MANEUVERS
ASYMMETRIC THRUST	INITIATING A ROLL BY RETARDING ONE OUTBOARD ENGINE
30 DEG CCW and 90 DEG CW	INDICATES A 30 OR 90 DEG CLOCKWISE OR COUNTER CLOCKWISE CONTROL INPUT AS INDICATED

(SEE TEXT FOR DETAILED DESCRIPTIONS)

TABLE III
SIMULATOR CONDITIONS

BASELINE	THE BASIC SIMULATOR WITH NO SOFTWARE MODIFICATIONS
K = .99,1.5, 1.75 or 1.99	MODIFIED VALUE OF THE TOTAL AILERON ROLLING MOMENT COEFFICIENT
4 OR 8 DEG DEFLECTION	AN INCREASED AILERON DEFLECTION OF 4 OR 8 DEG ON BOTH AILERONS, IN BOTH UP AND DOWN DIRECTIONS
SPLIT-FLAP	UTILIZING THE SPLIT-FLAP CONDITION

(SEE TEXT FOR DETAILED DESCRIPTIONS)

for all runs, which accounts for the lack of data in some areas.

Throughout the quantitative data acquisition phase, the pilots qualitatively evaluated the aircraft for controllability and workload. Although Handling Quality Ratings (HQR's) were not assigned, the various modified configurations were qualitatively compared to determine the optimum condition. In addition to the "canned" maneuvers, the pilots performed approaches, as well as precise heading and lineup changes, to determine the potential mission degradation that would occur during typical mission maneuvers.

2. Asymmetric Thrust

Another method of test that was briefly attempted was the utilization of asymmetric thrust to initiate a roll. Each of the four turboprop engine produces 4600 shaft horsepower (maximum rated). Any thrust differential that might occur between the two outboard engines would provide an unbalanced directional force due to the large lateral separation, resulting in a lateral force due to the dihedral effect. Additionally, since the propeller effect on the airflow over the wing produces a considerable amount of lift, a large lift differential will occur between the two wings, producing a larger rolling moment.

Several attempts were made to take advantage of this asymmetric thrust. Rolls were initiated from a straight and level condition by advancing one outboard throttle and retarding the other. This method of roll initiation did, in fact, create a significant roll rate. However, there were two problems experienced during this maneuver. First, the pilot workload was unacceptable. A reduction in workload would be realized if the copilot operated the throttles while the pilot controlled the aircraft. However, an unacceptable amount of crew coordination would be required and the throttle inputs and subsequent rolling moments would be delayed. A second problem existed in the large amount of altitude lost while performing this maneuver. Since the majority of the P-3 mission is spent low, over the water, altitude loss can be very dangerous. The difficulties associated with the use of asymmetric thrust for enhanced roll acceleration precludes this option from consideration.

C. BASELINE CONFIGURATION

A complete series of tests was conducted prior to modifying the simulator software in order to obtain baseline data. This data was used to evaluate the changes to the lateral response due to each of the software changes. Also, this baseline data was used for comparison with results from previous OFT tests, Ref 8. The results are tabulated in Table IV, and graphically displayed in Figure 5. As can be seen in the figure, the baseline simulator exhibited roll rates of approximately 20°/sec. throughout the airspeed range tested. This data agrees well with Ref. 8. The differences seen

TABLE IV
BASELINE CONFIGURATION

RUN NO.	PAGE NO.	KCAS	PRESSURE ALTITUDE (FT)	MANEUVER DESCRIPTION	BANK ANGLE (DEG)	ROLL VELOCITY (DEG/SEC)	ROLL ACCEL (DEG/S/S)	ROLLING MOMENT	AILERON POS (DEG)	WHEEL POS (DEG)	WHEEL FORCE (LB)	STOP WATCH TIMES (SEC) STEADY 60 DEG	STOP WATCH TIMES (SEC) INITIAL TEN DEG	STEADY STATE ROLLRATE (DEG/SEC)
3	107	199	512	0 TO 60 LT	-33.7	-24.586	0.0164	13568	-27.44	-105.02	-53.17			
35		200	500	0 TO 60 LT								3.83		15.67
41		275	500	0 TO 60 LT								3.69		16.26
42		275	500	0 TO 60 LT								3.50		17.14
45		275	500	0 TO 60 LT								3.63		16.53
50		350	500	0 TO 60 LT								3.46		17.34
51		350	500	0 TO 60 LT								3.25		18.46
1	102	195	524	0 TO 60 RT	58.4	17.492	-0.0290	-17216	25.57	96.24	38.02			
2	105	199	583	0 TO 60 RT	66.6	16.898	-0.0066	4416	24.17	93.27	46.87			
34		200	500	0 TO 60 RT								4.19		14.32
40		275	500	0 TO 60 RT								3.72		16.13
43		275	500	0 TO 60 RT								3.54		16.95
44		275	500	0 TO 60 RT								3.54		16.95
48		350	500	0 TO 60 RT								4.11		14.60
49		350	500	0 TO 60 RT								3.85		15.58
37		200	500	60 LT TO 60 RT								3.09	1.59	19.42
5	113	202	500	60 LT TO 60 RT	-63.6	1.750	0.2357	263808	14.16	57.81	45.97	6.72		8.93
46		275	500	60 LT TO 60 RT								2.99	1.52	20.07
53		350	500	60 LT TO 60 RT									1.45	
54		350	500	60 LT TO 60 RT								3.89	1.15	15.42
36		200	500	60 RT TO 60 LT									1.57	
4	109	244	500	60 RT TO 60 LT	33.0	-21.336	0.0116	15232	-19.73	-83.51	-51.98			
47		275	500	60 RT TO 60 LT								3.37	1.58	17.80
52		350	500	60 RT TO 60 LT								2.94	1.70	20.41
83	219	170	10000	30 DEG CCW	-65.1	-8.930	0.0115	4288	-7.58	-26.05	5.97			
85	221	177	10000	30 DEG CCW	-28.0	-9.141	0.0132	10816	-9.67	-34.86	-8.80			
84	220	178	10000	30 DEG CCW	-27.8	-7.992	0.0021	1920	-8.32	-30.72	-12.52			
39		200	500	30 DEG CCW										
86	222	175	10000	90 DEG CW	73.3	6.297	-1.0822	-34560	-29.93	-108.26	-53.52			
87	223	178	10000	90 DEG CW	44.5	25.031	-0.0098	-1688	29.07	104.72	43.08			
88	224	181	10000	90 DEG CW	56.8	23.937	-0.0144	-11456	27.52	100.41	41.95			
38		200	500	90 DEG CW										
89	225	173	10089	ASYMMETRIC THRUST	74.0	20.320	-0.6795	-51248	-15.86	-59.27	-29.95			
90	226	184	10031	ASYMMETRIC THRUST	70.8	34.937	-0.1327	-93440	12.36	41.12	-24.73			

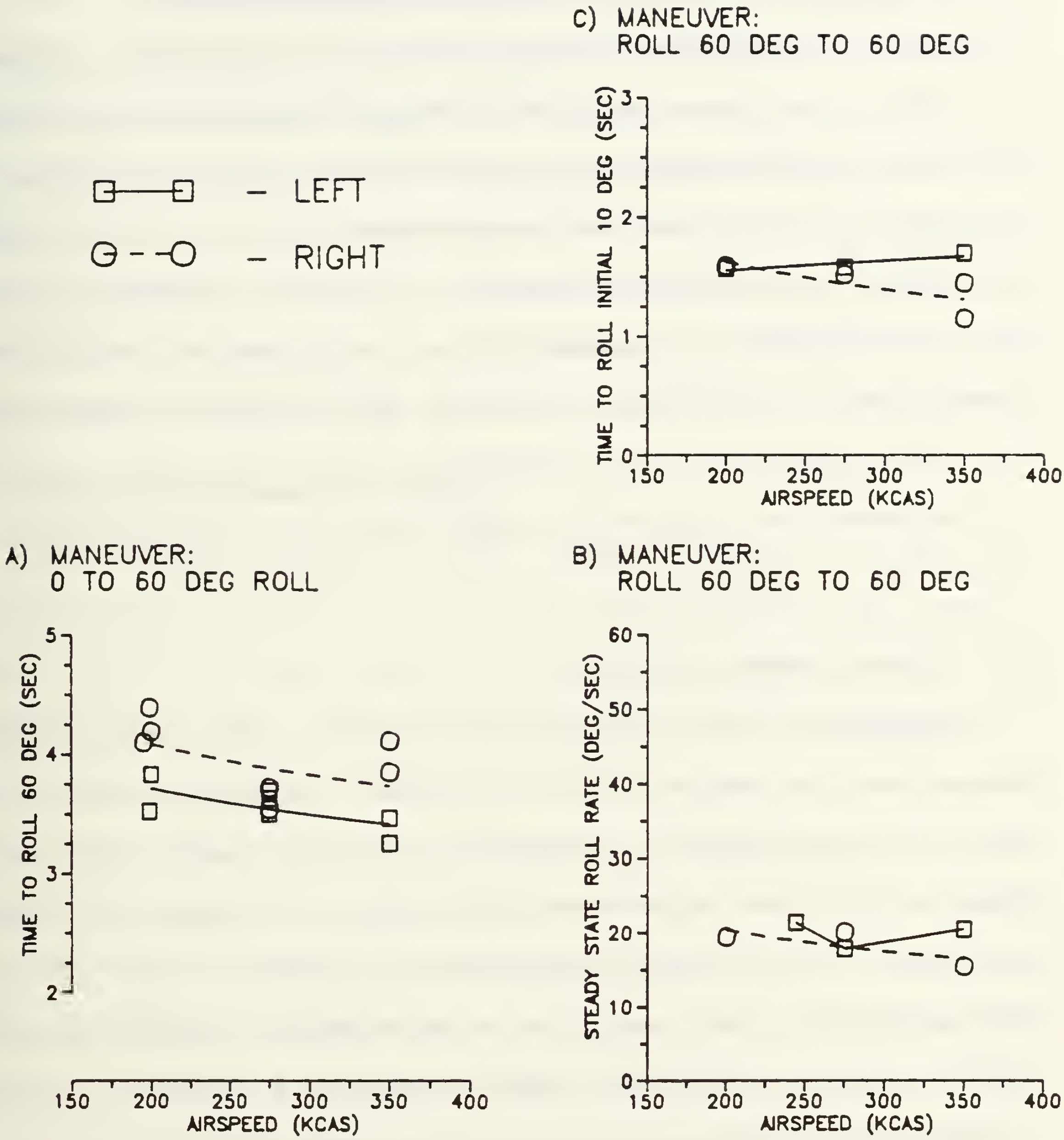

FIGURE 5
Baseline Configuration

between the left and right directions are due to the slipstream effects of the airflow over the wing caused by the turning propellers as well as the torque effects.

The 30° CCW and 90° CW maneuvers were duplicated from Ref. 8. For a 30° CCW input, the steady state roll rate was 7.7°/sec for the airplane and 11°/sec for OFT 2, compared to an average of 8.7°/sec for these tests. For a 90° CW input, the steady state roll rate was 21.6°/sec for the airplane and 18°/sec for OFT 2, compared to an average of 24.5°/sec for these tests. The results are not exact, but are acceptable for the purpose of this evaluation, since the major concern is the amount of improvement obtainable, and not the precise values of the results.

D. LATERAL CONTROL FORCES

Throughout the evaluation, the lateral control forces were excessive. Forces in excess of 50 lbs. (often as high as 70 lbs.) were required to establish full lateral control inputs. These high forces were noted for turns in either direction, over the full airspeed range tested and for all of the modifications to the simulator. These control forces resulted in slow inputs and eventual pilot fatigue. Slow inputs result in inadequate roll acceleration. Although the steady state roll rate will not be affected by this low roll acceleration, the initial aircraft response will be sluggish. A reduction in control forces would permit quicker inputs, resulting in increased roll acceleration for more aggressive maneuvering.

The control forces existing on the OFT's could not be changed. Therefore, the actual amount of reduction in control forces needed for the desired effect is not evident. However, it is obvious that any decrease in the lateral control forces would result in an improvement to the current roll response characteristics of the P-3. However, it should be noted that the lateral control forces exhibited by the flight simulator are somewhat greater than those of the actual P-3C aircraft.

E. MECHANICAL CHARACTERISTICS

The current lateral flight control system of the P-3 consists of a group of cables operating between the control wheel and an aileron booster unit. The movement is then transmitted to the ailerons via push-pull rods connecting to the aileron bellcrank assemblies. An inherent drawback with this type of system is a delay in transmitting control movement to the control surfaces, as well as the slow movement of the control surfaces. Therefore, it takes a relatively long time for the aileron to move through the full deflection range. Although step inputs were utilized to initiate all roll maneuvers, the inherent delay in transmitting the control movements to the ailerons and slow reaction time of the surfaces resulted in sluggish aircraft response. The precise time between control input and completion of control movement was not documented, but results indicated that almost five seconds was required. This time delay is not conducive to a "snappy" roll.

Altering the mechanical control system of the aircraft in such a way that would reduce the transmission delay and increase the rate of movement of the aileron would contribute to an increased lateral control response. This would allow for quicker aircraft response to pilot input. As with the control forces, there was no way to evaluate this type of change on the flight simulator. Therefore, the extent of control system modifications required to create the desired response is not known. However, advances in technology since the initial installation of this system into the P-3 make it a viable option. It is recommended that further evaluation be conducted to determine the possible results of such a modification.

F. EFFECTS OF CHANGING THE AILERON MOMENT COEFFICIENT

1. Description of Test

The first software modification to the simulator, involved a systematic increase in the total rolling moment coefficient (C_l). Evaluations of the different C_l's were conducted utilizing the simulator. The changes to the software simulated a number of possible modifications to the actual airframe which would result in a larger contribution of the lateral control surfaces to the rolling moment of the aircraft. Such changes could include a larger aileron or the addition of other control surfaces such as spoilers.

Table V shows the section of software that was changed during this portion of testing. The constant 'K' in this software is a coefficient representing the magnitude of the C_l due to flap position. For most of the evaluation, the flaps were retracted, so this value of 'K' did not change and could be easily modified to vary C_l. This value of 'K' was incrementally increased from the original value to simulate the higher rolling moment coefficient. (Doubling the value of 'K' has the effect of doubling C_l.)

TABLE V
SIMULATOR SOFTWARE FOR MODIFYING
THE ROLLING MOMENT COEFFICIENT

```
;&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
        .MMEQ   FCLDA = (FCLDAR - FCLDAL)*K - 0.0004*FDATT        ;;00207A
        .MMEQ   FLAPS=0-10,K=.9;FLAPS=18-40,K=.8                  ;00207A
;&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
        .MMEQ
        MOV     FCLDAR,R0          ;-03   -03  CL DELTA AIL. RIGHT
        SUB     FCLDAL,R0          ;-03   -03  FCLDAR - FCLDAL
        MOV     F001,R2            ;+00    I.V. FOR FLAPS            ;00207A
        CMP     #0.125B00,R2       ;       FLAPS<10                  ;00207A
        BMI     80$                ;       BR IF FLAPS>10            ;00207A
        MOV     #0.125B00,R2       ;       LOWER LIMIT               ;00207A
80$:    CMP     #0.25B00,R2        ;       FLAPS>18                  ;00207A
        BPL     90$                ;       BR IF FLAPS<18            ;00207A
        MOV     #0.25B00,R2        ;       UPPER LIMIT               ;00207A
90$:    MOV     #1.0B01,R4         ;+01                              ;00207A
        MUL     #0.8B00,R2         ;+00+00+01 .1,.2                  ;00207A
        SUB     R2,R4              ;+01  R4=K=.9(0,10) OR =.8(18,40;00207A
        MUL     R4,R0              ;+01-03-01  R0=K*(CLDAR-CLDAL)    ;00207A
        ASHC    #2,R0              ;-01   -03                        ;00207A
        MOV     FDATT,R2           ;+05   +05 DELTA AIL. TRIM TAB
        MUL     #+0.0004B-09,R2    ;-09+05-03 -0.0004* FDATT         ;00053A
        SUB     R2,R0              ;-03   -03
        MOV     R0,FCLDA           ;-03   -03 STORE FCLDA
        .MMEQ
```

For each value of 'K', the described series of maneuvers was conducted to determine the resulting roll rate and acceleration, while the effect on the flying qualities of the airplane was qualitatively evaluated.

2. Results

A tabulated summary of the results of this test is shown in Appendix A, Table III. These times are graphically displayed in Figures 6 and 7, for the left and right directions respectively. The baseline condition is included for comparison.

As expected, an increase in the value of 'K' generally resulted in enhanced roll response. The pilots found that a value of 'K' = 1.99 provided an uncontrollable flight regime. The aircraft was too responsive, resulting in constant over-correction by the pilots and hence the inability to maintain a wings level flight condition. At this value of 'K', the time to roll the initial 10° and the steady state roll rate do not appear to be consistent with the trends established by the other values of 'K'. However, this condition is not considered to be as quantitatively accurate as the others because the pilots anticipated overshooting 70° angle of bank (resulting in a crash condition on the simulator). Therefore, the control inputs were removed prematurely, decreasing the roll response.

Qualitatively, as the value of 'K' was increased from the original value, the aircraft became more sensitive in the

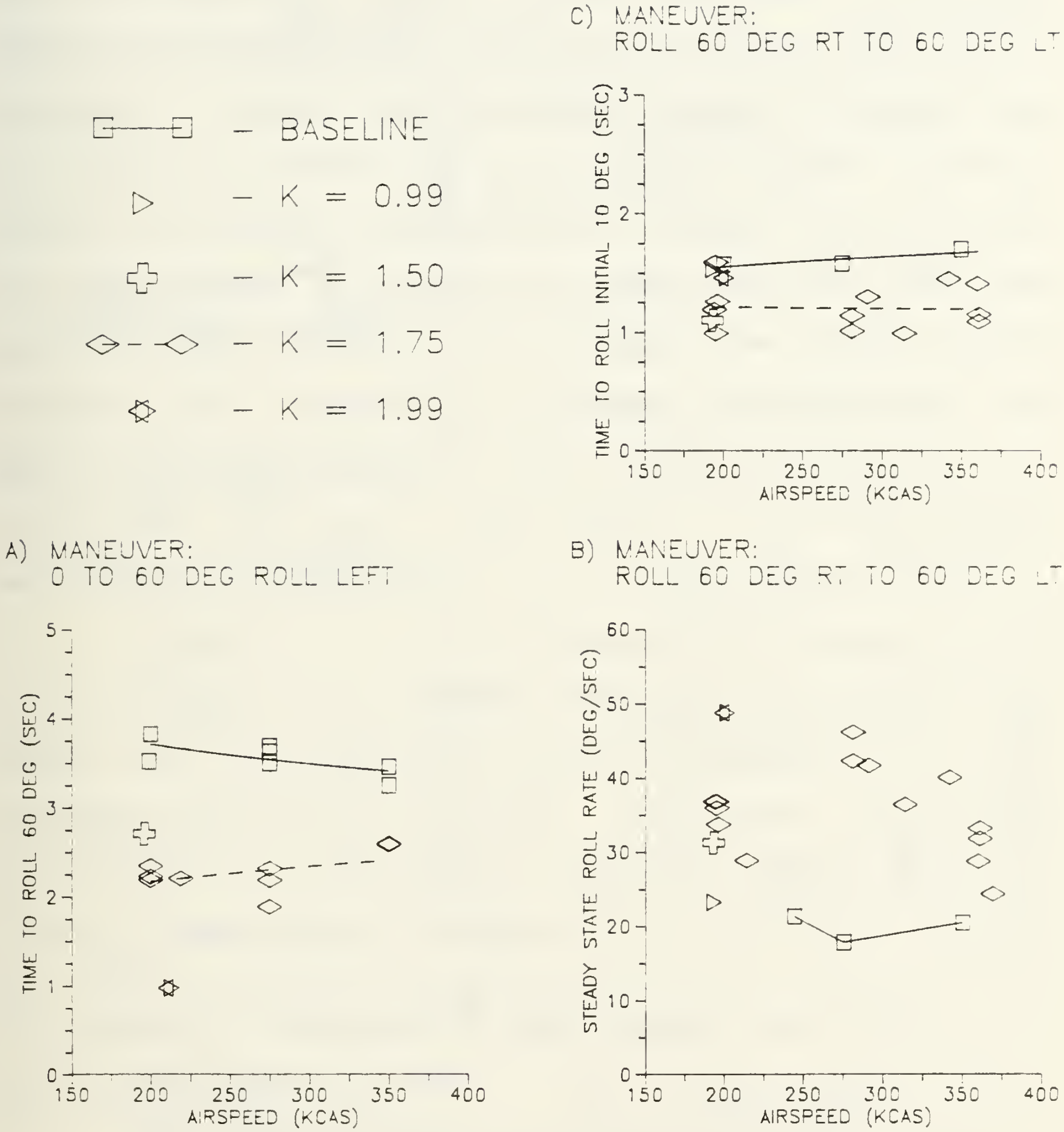

FIGURE 6
Effects Of Modifying The Rolling Moment Coefficient
(Left Turns)

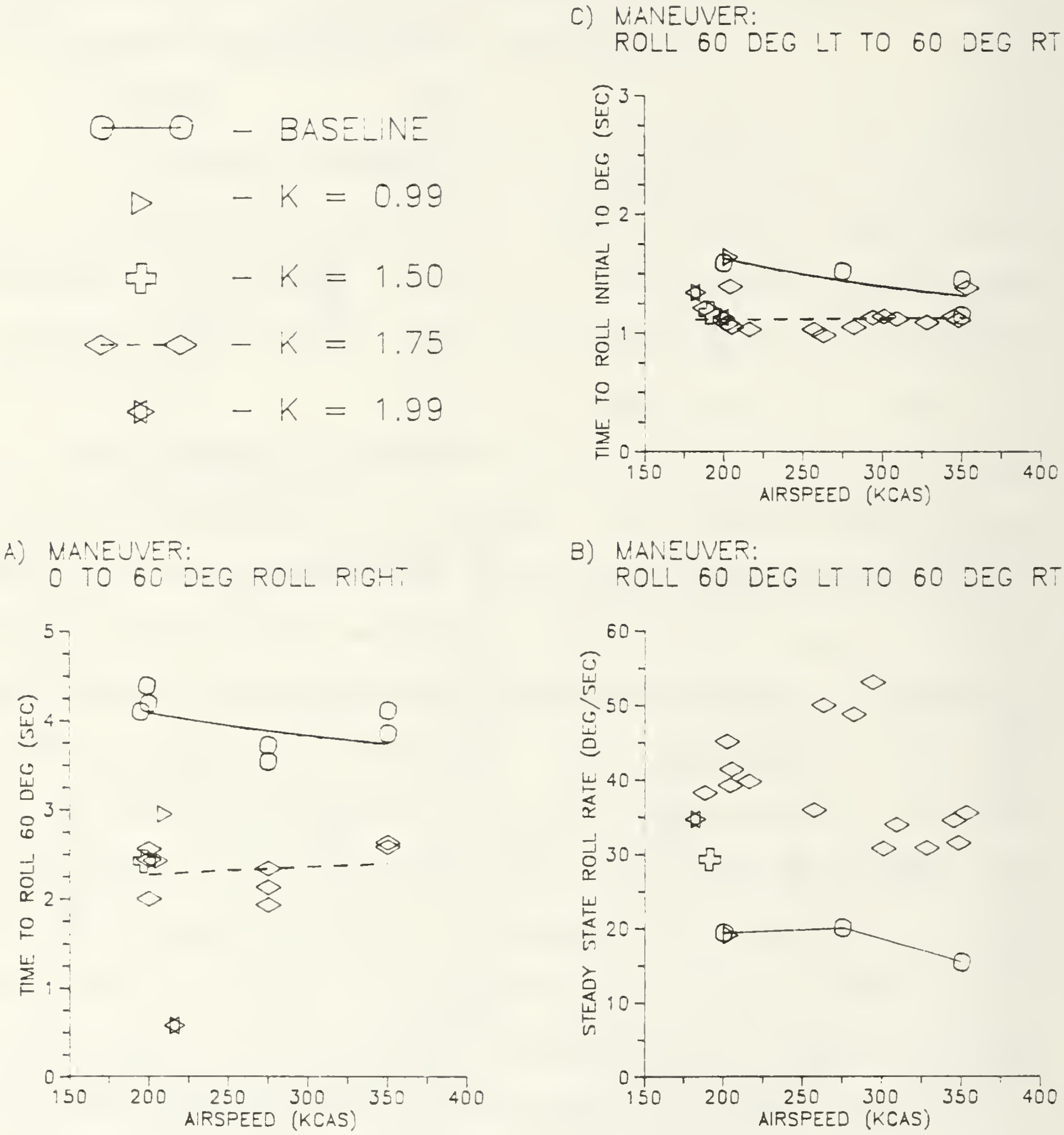

FIGURE 7
Effects Of Modifying The Rolling Moment Coefficient
(Right Turns)

lateral axis. A value of 'K' = 1.75 provided a controllable aircraft, without an unreasonable increase in workload, and exhibited excellent lateral flying qualities. The steady state roll rate was found to be about 35°/sec. (dependent on airspeed). The roll rate was approximately 75% higher than the baseline condition for all airspeeds tested. Although there was a tendency to slightly over control the aircraft at 60° angle of bank, an approach to landing was safely performed with no lineup problems. In general, the pilots quickly adapted to the increased roll response. As described by one pilot: "It's like driving a car with power steering for the first time - you tend to over control it initially, but you get used to it quickly."

A value of 'K' = 1.75 represents an increase in the total aileron rolling moment coefficient of 194% for the normal flap (0°) condition and an increase of 219% in the approach flap (18°) condition. Therefore, doubling the current aileron rolling moment coefficient of the P-3 appears to be an ideal goal for changes to the P-3 lateral axis.

G. EFFECTS OF CHANGING THE TOTAL AILERON DEFLECTION

1. Description of Test

The second software modification was an increase in the total aileron deflection of the simulator. The software was modified in such a way as to provide increased total deflection on the left and right ailerons, as well as larger aileron deflections for a given control input. The additional deflections were applied in both the positive and negative directions. Additional deflections of both 4° and 8° were investigated. The current limits of the aileron travel are compared to the modified values in Table VI.

TABLE VI
LIMITS OF AILERON DEFLECTION

	RIGHT			LEFT	
	UPPER (DEG)	LOWER (DEG)	AVERAGE (DEG)	UPPER (DEG)	LOWER (DEG)
CURRENT	16.00	20.00	±18.69	15.50	23.25
4° ADDITIONAL	20.00	24.00	±22.69	19.50	27.25
8° ADDITIONAL	24.00	28.00	±26.69	23.50	31.25

AVERAGE - USED IN THE AIRFOIL CODE EVALUATION, SINCE THE EFFECT OF THE TURNING PROPELLER IS NOT CONSIDERED.

The control laws of the OFT did not account for the possibility of flow separation with the increased deflection. The tests were conducted with the assumption that a stall condition did not occur. However, the stall characteristics of the airfoil were accounted for by evaluating the same deflections with a 2-D airfoil code that will be discussed later in this report.

The described series of maneuvers was conducted to determine the resulting roll rate and acceleration, while the effect on the flying qualities of the airplane was qualitatively evaluated.

2. Results

A tabulated summary of the results of this test is shown in Table VII. The average values are included because the effect of the turning propellers were not considered during the later evaluation with an airfoil code. These values will be used for comparison with those results. A graphical representation of these results compared to the baseline aircraft is shown in Figures 8 and 9 for left and right turns respectively. As can be seen, the additional deflection does, indeed, increase the steady state roll rate of the P-3 by as much as 50%, without unreasonably increasing the workload.

Restrictions within the OFT hardware, limited the total increase in aileron deflection to 16° on each side. This yielded an increased deflection of a positive 8° on one side and a negative 8° on the opposite side for a full control input. This maximum increase in deflection is not considered to be the limiting case as far as lateral response or pilot workload is concerned. However, the effects of the local flow separation must still be considered.

TABLE VII
EFFECTS OF ADDITIONAL AILERON DEFLECTION

RUN NO.	PAGE NO.	KCAS	PRESSURE ALTITUDE (FT)	MANEUVER DESCRIPTION	ADDITIONAL DEFLECTION	BANK ANGLE (DEG)	ROLL VELOCITY (DEG/SEC)	ROLL ACCEL (DEG/S/S)	ROLLING MOMENT	AILERON POS (DEG)	WHEEL POS (DEG)	WHEEL FORCE (LB)	STOP WATCH TIMES (SEC) STEADY 60 DEG	INITIAL 10 DEG	STEADY STATE ROLLRATE (DEG/SEC)
29	131	218	355	0 TO 60 LT	4 DEG	-58.1	-24.930	0.0014	0	-25.64	-102.95	-59.11	3.24		18.52
33		200	500	0 TO 60 LT	4 DEG								3.19		18.81
32		200	500	0 TO 60 RT	4 DEG								2.59		23.17
28	130	223	414	0 TO 60 RT	4 DEG	15.9	22.766	0.1064	82048	25.86	105.89	66.70	3.40		17.65
31	133	192	701	60 LT TO 60 RT	4 DEG	27.4	19.477	-0.0092	-5056	29.00	109.35	54.30	3.00	1.18	20.00
30	132	196	484	60 RT TO 60 LT	4 DEG	-39.9	-24.219	-0.0461	-34816	-25.88	-99.05	-51.48	2.76	1.32	21.74
117		200	500	0 TO 60 LT	8 DEG								3.49		17.19
114		200	500	0 TO 60 LT	8 DEG								3.29		18.24
115		200	500	0 TO 60 LT	8 DEG								3.33		18.02
116		200	500	0 TO 60 LT	8 DEG								3.52		17.05
113		200	500	0 TO 60 LT	8 DEG								3.25		18.46
110		200	500	0 TO 60 RT	8 DEG								3.19		18.81
111		200	500	0 TO 60 RT	8 DEG								3.33		18.02
109		200	500	0 TO 60 RT	8 DEG								3.21		18.69
118		200	500	0 TO 60 RT	8 DEG								3.56		16.85
112		200	500	0 TO 60 RT	8 DEG								3.37		17.80
132	253	279	500	60 LT TO 60 RT	8 DEG	48.9	27.039	0.0216	15488	18.79	84.76	67.56	2.50	1.32	24.00
123	244	201	500	60 LT TO 60 RT	8 DEG	47.3	14.242	-0.2101	-154176	10.41	40.78	21.94	3.25	1.70	18.46
125	246	208	500	60 LT TO 60 RT	8 DEG	42.0	22.344	0.0000	640	25.56	101.16	60.84	2.92	1.88	20.55
122	243	204	500	60 LT TO 60 RT	8 DEG	48.2	21.453	-0.0246	-21952	19.48	75.33	30.59	2.96	1.91	20.27
130	251	308	500	60 LT TO 60 RT	8 DEG	39.1	18.844	0.0122	6976	13.59	64.87	60.95	3.41	1.52	17.60
129	250	283	500	60 LT TO 60 RT	8 DEG	24.0	17.312	-0.0585	-48000	12.08	55.52	48.34	3.70	1.26	16.22
131	252	298	500	60 LT TO 60 RT	8 DEG	49.4	22.781	0.0117	9600	16.56	78.83	80.94	2.91		20.62
124	245	203	500	60 LT TO 60 RT	8 DEG	45.2	26.984	-0.0387	-26496	27.11	104.87	55.72	2.84	1.47	21.13
121	242	200	500	60 RT TO 60 LT	8 DEG	-47.5	-24.969	0.0239	11712	-25.65	-97.98	-44.06	2.68	1.58	22.39
126	247	284	500	60 RT TO 60 LT	8 DEG	-52.8	-30.625	-0.0252	-17856	-18.93	-86.01	-70.05	2.03	1.34	29.56
127	248	299	500	60 RT TO 60 LT	8 DEG	-80.5	-16.250	0.6794	519040	-2.03	-7.94	5.02	2.62	1.44	22.90
119	240	247	500	60 RT TO 60 LT	8 DEG	-37.2	-22.867	-0.0155	-12544	-19.39	-82.45	-50.69	2.84	1.33	21.13
120	241	190	500	60 RT TO 60 LT	8 DEG	-50.4	-24.922	0.0621	42048	-26.17	-98.42	-46.50	2.83	1.57	21.20
128	249	287	500	60 RT TO 60 LT	8 DEG	-81.1	15.937	0.5872	445568	16.39	75.98	65.05	2.27	1.63	26.43

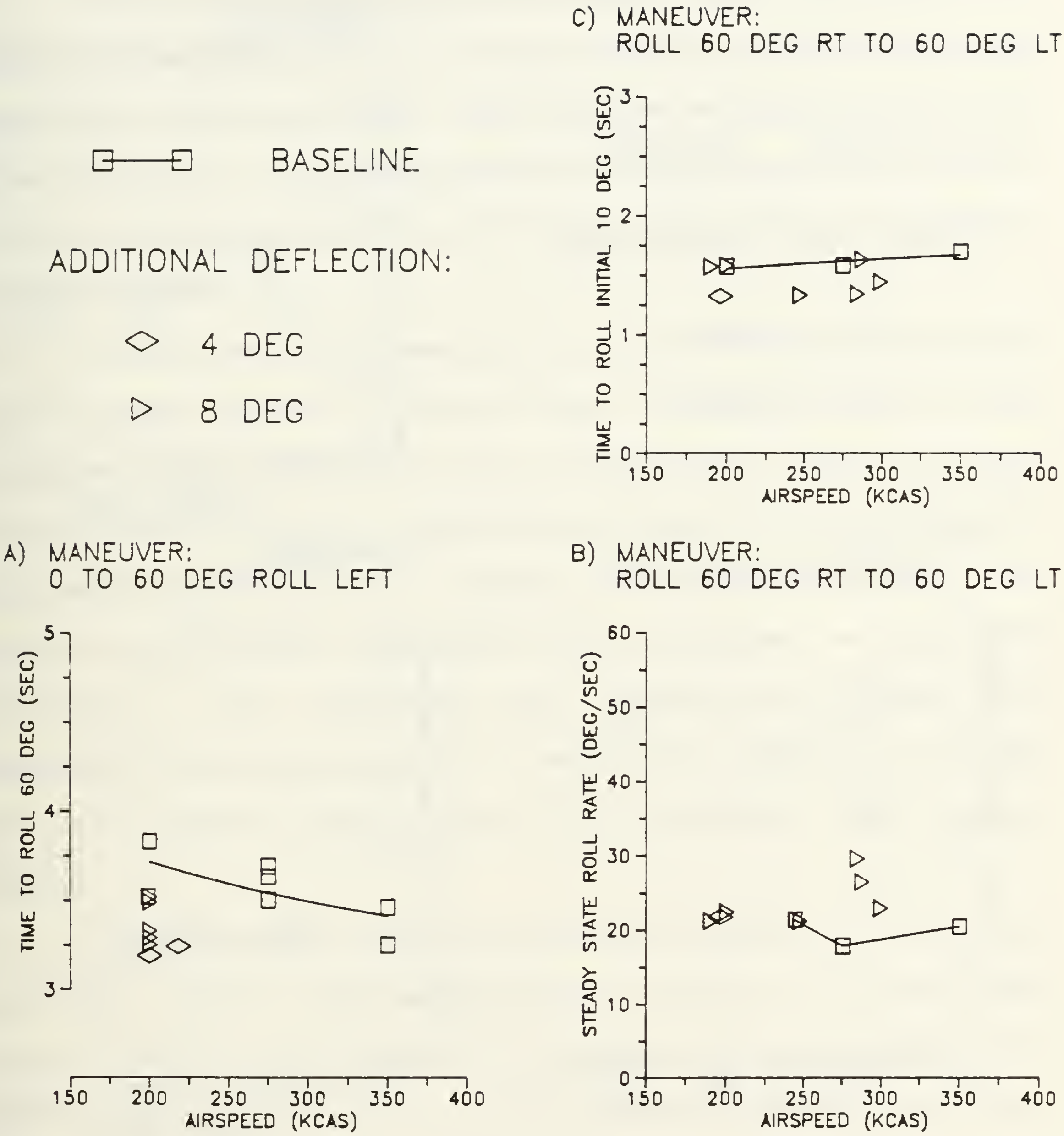

FIGURE 8
Effects Of Increasing The Maximum Aileron Deflection
(Left Turns)

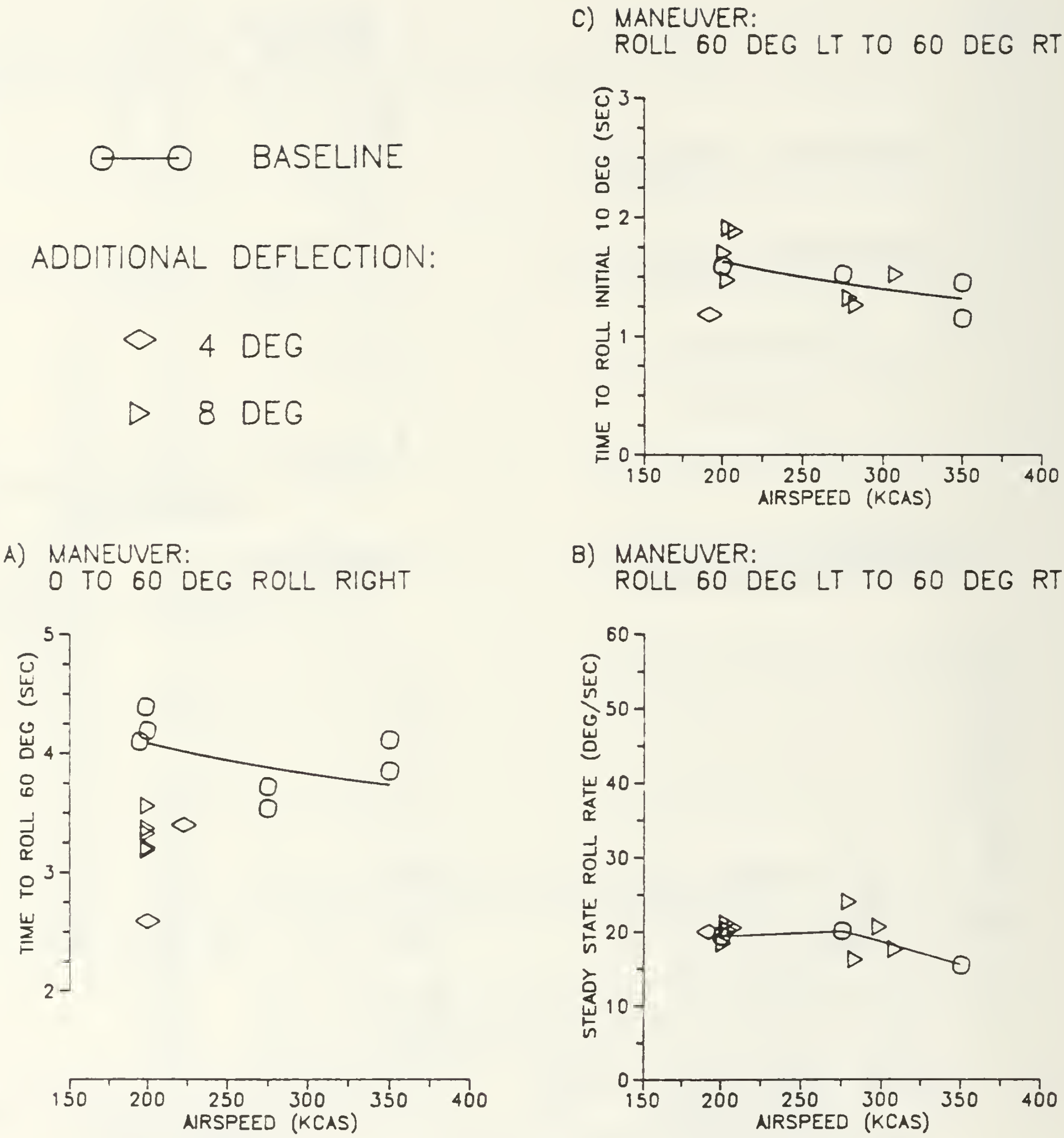

FIGURE 9
Effects Of Increasing The Maximum Aileron Deflection
(Right Turns)

H. EFFECTS OF USING FLAPS FOR ROLL ASSIST

1. Description of Test

One of the emergency procedures (EP) incorporated in the P-3C simulator is a split-flap condition. This split-flap condition occurs when one flap extends or retracts farther than the other. This EP was used to evaluate the contribution to roll response induced by utilizing the flaps as a lateral control surface.

Actual modifications to the aircraft would consist of active flaps instead of split-flaps. An active flap is one which responds to lateral control inputs, much like an aileron under certain conditions where the flap position is a function of control deflection. However, limitations within the software prohibited simulation of an actual active flap condition. The flaps were set asymmetrically about the maneuver flap position (the 10° position). The left flap was set at 6° and the right flap at 14°, inducing a left rolling moment.

The maneuver flap position was selected as the center position due to considerations of actually incorporating active flaps on the aircraft. It would not be beneficial to utilize active flaps during all phases of the mission. As part of the active flap system, it would be necessary to "sense" the need for active flaps. Sensors could be installed to evaluate the lateral input and activate the active flaps at a predetermined value of input rate or force. However, this could result in excessive complexity. A simpler method seems to be utilization of the maneuver flap position to demand the active flap condition. This flap position is rarely used during the mission since it creates only a 2 to 3 knot reduction in stall speed and increases fuel usage due to the higher power settings required. When the mission dictates the possible need for increased roll response, the pilot could select this maneuver flap position. The slight loss in performance due to the increased drag could be justified by the increase in roll rate when defensive maneuvering is anticipated.

Only left turns were evaluated for this condition due to the rolling moment induced by the split flap. Each test maneuver was initiated from a steady, level 60° angle of bank right turn. Qualitative evaluation was limited since the flaps were stationary throughout the maneuver. While the split-flaps reduced the workload during left turns, right turns were very difficult due to the induced left rolling moment. The extremely high workload required to stop the left turn or return to a wings level condition was not representative of an actual aircraft incorporating active flaps.

2. Results

A summary of the results of this test is shown in Table VIII and graphically displayed in Figure 10. As expected, the use of flaps increased the roll response of the aircraft. The time to roll 60° was decreased by a full second, from 3.75 sec. to 2.75 sec. The time to roll the initial 10° was reduced from 1.5 sec. to just over 1 sec. and the steady state roll rate was increased by about 50% (30°/sec vice 20°/sec). The use of active flaps instead of stationary flaps would provide this enhanced lateral response, without the added workload experienced with the stationary split-flap. However, extrapolation from the split flap to active flap conditions must be handled with caution. Care should be used when making any conclusions, since very little data was obtained during this portion of the tests due to excessive pilot workload in the split flap condition.

TABLE VIII
RESULTS OF SPLIT FLAP TESTING

RUN NO.	KCAS	STEADY STATE ROLL RATE (DEG/SEC)	PRESSURE ALTITUDE (FT)	MANEUVER DESCRIPTION	STOP WATCH TIMES (SEC) STEADY 60 DEG	INITIAL 10 DEG
133	190	23.90	500	0 TO 60 LT	2.51	
134	190		500	0 TO 60 LT	2.75	

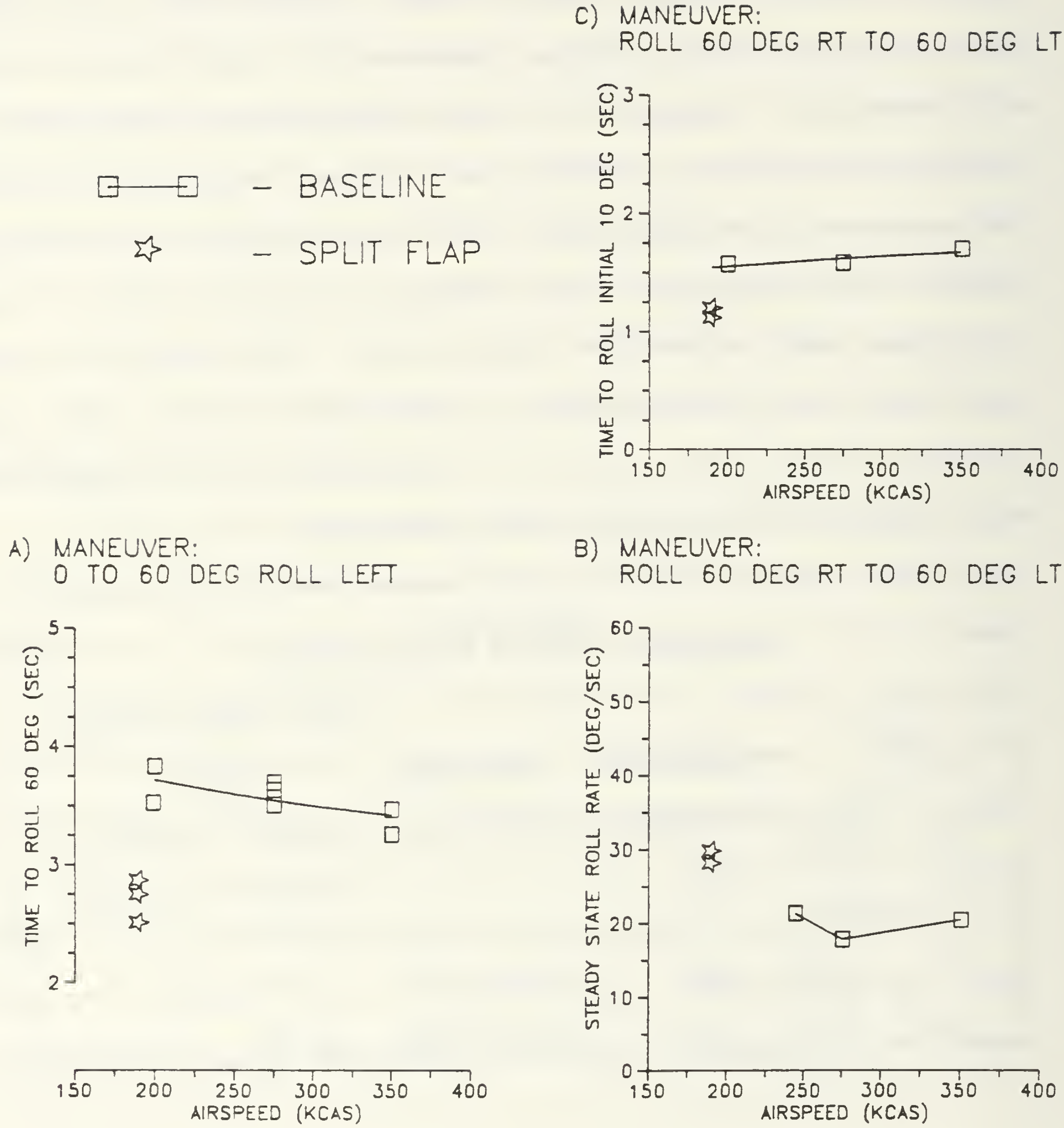

FIGURE 10
Effects Of Utilizing A Split Flap Configuration

IV. AIRFOIL CODE

Having established a "target" roll response, it was necessary to determine to what extent the current wing of the P-3 would have to be modified to reach this goal. An airfoil computer code was utilized to determine the changes necessary to produce an aileron rolling moment equivalent to twice the current value. If these changes were found to be too drastic, the computer code could also be utilized to determine the rolling moment which could be generated by reasonable alterations. The code could also predict the effect of additional aileron deflection on the airflow over the wing.

A. DESCRIPTION OF AIRFOIL CODE

To evaluate these various modifications, a 2-D airfoil computer code was utilized. This code, called SEARCHSE, was developed as part of a Masters' Thesis at Texas A & M and is described in detail in Refs. 11 and 12. This code was chosen for this evaluation for two reasons. First, the code is designed to evaluate multi-element airfoils and the resulting flow over a deflected surface. Secondly, the code will predict flow separation.

Several inputs are required to run this program, including the geometry of the airfoil, angle of attack, Mach No., stagnation pressure and temperature, and kinematic viscosity. The surface pressure distribution is calculated, from which the lift, drag and pitching moment coefficients are derived. For this evaluation, the lift coefficient was the primary concern.

B. MODIFICATIONS AND VERIFICATION

Modifications to the program were required to tailor it to the specific needs of this evaluation and provide compatibility with the computer system at USNPGS. The major modification consisted of deleting all references to plotting within the program because the plot sub-program which is called for in SEARCHSE was not available on the USNPGS computer system. The other modifications were minor in nature and were designed to correct several format type errors discovered when operating on this computer system.

Once these modifications were complete, it was necessary to verify the accuracy of results obtained from the modified SEARCHSE program. The non-dimensional coordinates for the NACA 0012 airfoil were input to the program and the results were compared to experimental results. Reference 13 shows theoretical results for the NACA 0012 airfoil for a Reynolds No. of 9×10^6. The airspeed and temperatures that were chosen for input to the program provided a Reynolds No. of 8.96×10^6. Angles of attack were varied until separation was predicted in both the positive and negative directions. Results showed very close agreement with theory for all angles of attack evaluated. This close agreement verified the accuracy and justified use of the program for evaluating airfoil modifications.

C. METHOD OF EVALUATION

Once the accuracy of the program was confirmed, several airfoil sections were evaluated with a variety of trailing edge deflections and sizes. All inputs to the program were for sea-level standard day conditions. These section results were then mathematically combined to determine the overall wing effect.

A fortran program, WINGIT, was created that could modify the basic NACA 0012 airfoil as required for this evaluation. The program could provide a change in the thickness of any specific airfoil, an aileron deflection, and an altered aileron chord size. This program is included as Appendix B. This program was not designed to optimize the airfoil geometry with these changes incorporated. The results are, therefore, not exact, but for the purposes of this evaluation, the geometry generated by the program is satisfactory. Before making any actual changes to the aileron shape, it would be important to determine the optimal airfoil geometry to prevent flow separation.

Initially, the NACA 0012 airfoil coordinates were input to WINGIT to produce the basic NACA 0013 and NACA 0014 airfoils. (All three of these airfoils are from the same family of airfoils and differ only by relative thickness.) These airfoils were then run through SEARCHSE to determine the effect of thickness on the coefficient of lift C_L. The effect was minimal. Since the airfoil sections of the P-3 wing vary linearly from the NACA 0012 at the wingtip, to the NACA 0014 at the wing root, it was decided to use the NACA 0013 for all evaluations to approximate average results.

The NACA 0013 airfoil coordinates were then run through the WINGIT program several times to create a variety of aileron size and deflection combinations. Five different aileron sizes were evaluated. These sizes were increased in 25% increments, from a relative aileron chord of 1.00 (original size) to 2.00 (double the original aileron).

The angle of attack was varied from -6° to +6°. Higher angles of attack were not investigated since the normal cruise angle of attack of the P-3 is relatively low.

The results of this portion of the evaluation are discussed in the following sections. Although only typical results are shown and discussed, Appendix C contains a complete set of data. All trends shown in the typical results are consistent for all conditions evaluated.

D. RESULTS

1. Effects of Varying the Aileron Size

As stated earlier, there is no room for spanwise growth of the lateral control surfaces along the wing. For this reason, only the effect of chordwise aileron increases was evaluated. Typical results of the effect of varying the aileron chord size are graphically illustrated in Figure 11A for an angle of attack of 0°, and in Figure 11B for an aileron deflection of 20°. As can be seen in the two graphs, increasing the aileron size results in a larger C_L for all angles of attack and aileron deflections as expected. For a 25% increase in aileron size, the value of C_L was increased by 0.1. Doubling the size of the aileron resulted in an increase of 0.3 for the same deflection. An increase of 100% produces an airfoil which is 43% of the airfoil section. This may be excessive for the average airfoil, based on the geometry of todays' general transport type aircraft. A more reasonable size may be to increase the aileron chord by 50%, which provides an aileron that is only 36% of the total chord. The value of C_L for this condition is increased by 0.2. However, this C_L is acting over a larger area, to yield a much better result. To determine the actual results, the following equation for lift was used:

$$L = 1/2\ C_L\ (\text{density})\ V^2\ S$$

As far as the rolling moment is concerned, the lift produced by that part of the wing not covered by the aileron is cancelled between the left and right side. Therefore, only the lift produced by the aileron sections is considered in the calculations. For simplicity, and due to inherent problems in SEARCHSE (which will be discussed later), calculations were performed for a zero angle of attack airfoil with 20° of aileron deflection in both the up and down directions.

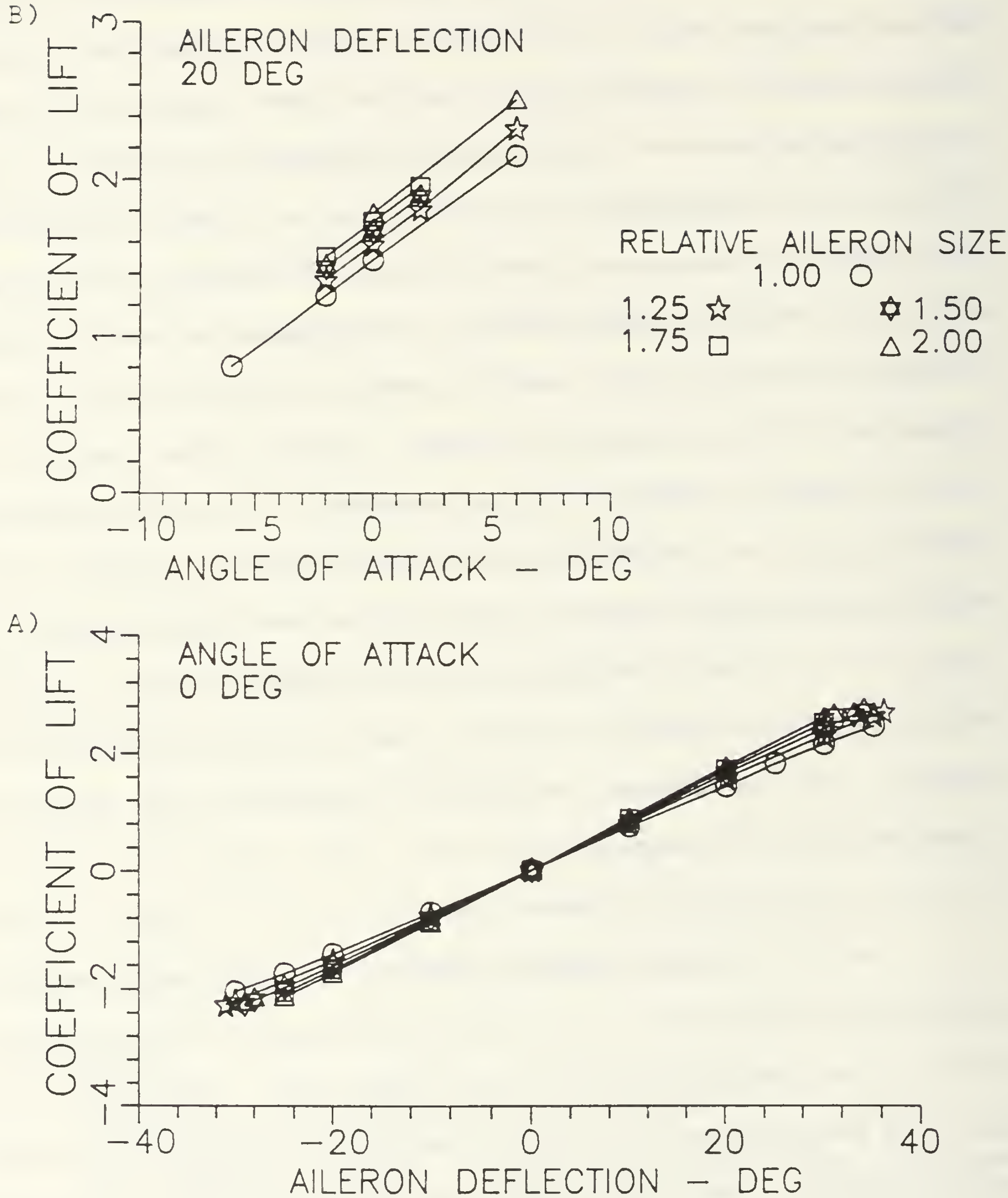

Figure 11
Effect of Varying the Relative Aileron Size

Results are shown in Table IX. As seen in this table, increasing the aileron size by 50% alone (no additional deflection or other aircraft modifications), yields an increase in rolling moment of almost 29%. If combined with other modifications, this would be even higher.

TABLE IX
EFFECT OF INCREASED AILERON SIZE ON LIFT (1)

RELATIVE AILERON SIZE	CL	AREA Ft^2	LIFT Lb	INCREASE FROM 1.00 %	AVERAGE INCREASE %
1.00	1.4839	166.56	32965.74		
1.00	-1.4095	166.56	-31312.90		
1.25	1.5834	178.01	37594.34	14.04%	14.68%
1.25	-1.5209	178.01	-36110.42	15.32%	
1.50	1.6629	189.46	42021.46	27.47%	28.62%
1.50	-1.6081	189.46	-40636.66	29.78%	
1.75	1.7275	200.91	46292.12	40.42%	42.00%
1.75	-1.6778	200.91	-44960.30	43.58%	
2.00	1.7807	212.36	50437.20	53.00%	54.99%
2.00	-1.7355	212.36	-49156.93	56.99%	

(1) ALL DEFLECTIONS ARE ±20°
ANGLE OF ATTACK = 0°

2. Effect of Varying the Aileron Deflection

Typical results for the effect of increasing the aileron deflection are illustrated in Figure 12A for an angle of attack of 0° and 12B for a relative aileron size of 1.50. An increase in aileron deflection increases the value of C_L by as much as 2 (for a 30° aileron deflection in both the positive and negative directions). The deflection angle which caused predicted flow separation varied depending on aileron

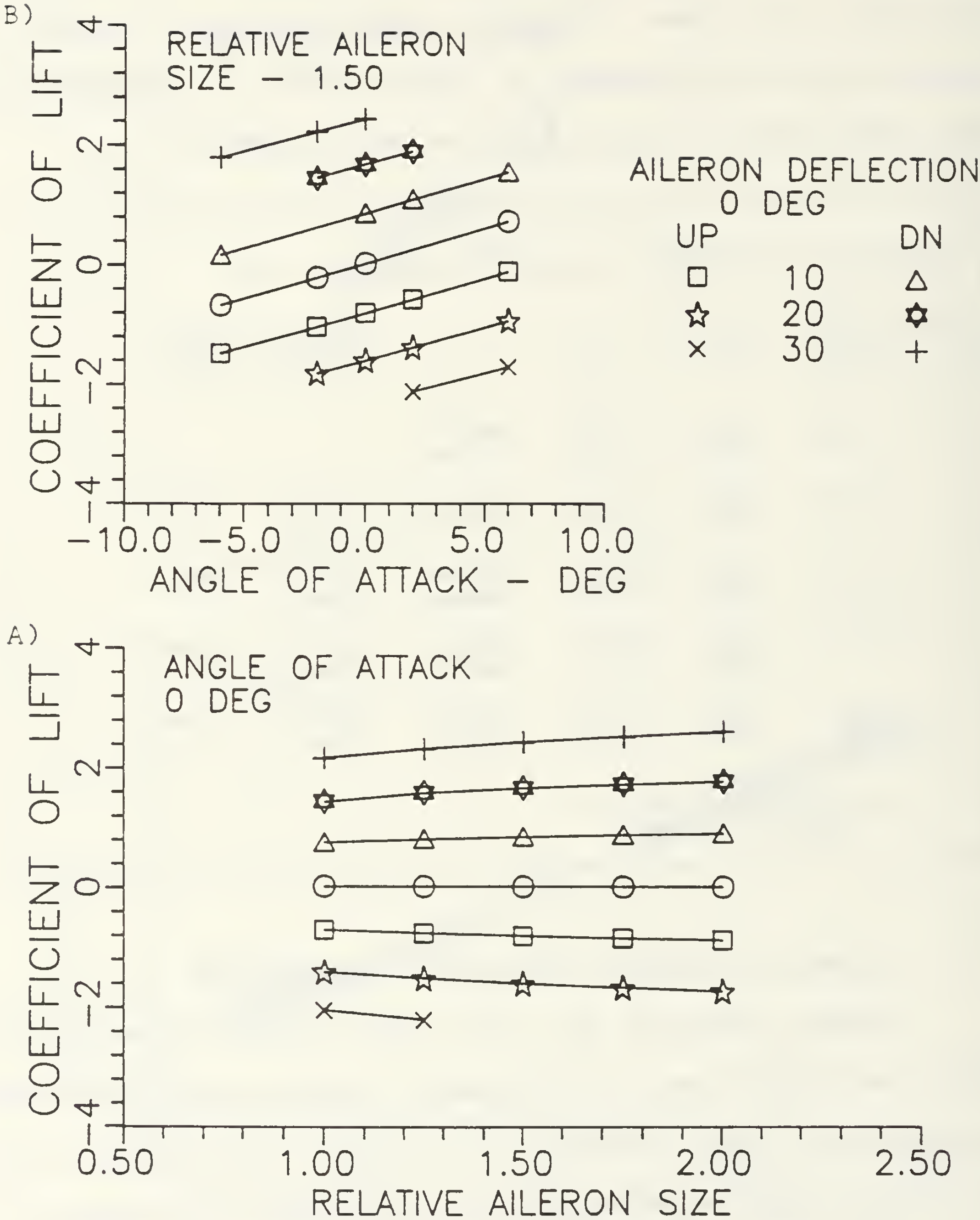

Figure 12
Effect of Varying the Aileron Deflection

size and angle of attack. Table X is a summary of these results. (As seen in Table X not all conditions were run to the point of predicted flow separation.) Also apparent in this table is a problem inherent to the SEARCHSE program. A symmetric airfoil at 0° angle of attack should see the same magnitude of C_L for equal aileron deflections in opposite directions. Additionally, an angle of attack of 6° should produce equal but opposite values of C_L when compared to -6°. The results from the program do not confirm this. This problem was not identified during the verification phase, since no theoretical data was found for ailerons with deflected surfaces. For the purposes of this evaluation, averages were taken for these contradicting results (up to 4% differences when comparing the improvements). For the tests at low angle of attack (0° and ±2°) it is apparent that deflections of up to ±25° do not cause predicted flow separation. This represents an average increase in the aileron deflection of more than 6° when compared to the average values shown in Table VI. From Figure 12 this results in an increase in C_L from about 1.6 to slightly over 2.

3. Effects of Varying the Angle of Attack

Typical results of the effect of varying the angle of attack are graphically illustrated in Figure 13. As expected, an increase in the angle of attack increased the value of C_L. The increase is constant regardless of the aileron size for deflections up to 25°. Therefore, the cruise angle of attack

TABLE X
LIMITING AILERON DEFLECTION ANGLES

TEST CASE	RELATIVE AILERON SIZE	ANGLE OF ATTACK	AILERON DEFLECTION	COEFFICIENT OF LIFT	CONDITION (1)
A	1.00	0	37	2.6186	L
A	1.00	0	-32	-2.1885	L
B	1.00	2	35	2.7201	L
B	1.00	2	-35	-2.2140	N
C	1.00	-2	40	2.6280	N
C	1.00	-2	29	-2.1928	L
D	1.00	6	26	2.5277	L
D	1.00	6	-40	-2.1638	N
E	1.00	-6	46	2.7272	L
E	1.00	-6	-20	-2.1091	L
F	1.25	0	36	2.7166	L
F	1.25	0	-31	-2.2717	L
G	1.25	2	33	2.7325	L
G	1.25	2	-37	-2.4650	L
H	1.25	-2	39	2.7087	L
H	1.25	-2	-26	-2.1495	L
I	1.25	6	22	2.3874	L
I	1.25	6	-40	-2.2739	N
J	1.25	-6	40	2.3868	N
J	1.25	-6	-17	-2.0148	L
K	1.50	0	34	2.7227	L
K	1.50	0	-29	-2.2631	L
L	1.50	2	28	2.5702	L
L	1.50	2	-33	2.3450	L
M	1.50	-2	41	3.0097	L
M	1.50	-2	-24	-2.1112	L
N	1.50	6	17	2.0905	L
N	1.50	6	-44	-2.6939	L
O	1.50	-6	46	2.9364	L
O	1.50	-6	-15	-1.9393	L
P	1.75	0	31	2.5980	L
P	1.75	0	-26	-2.0633	N
Q	1.75	2	25	2.3458	L
Q	1.75	2	-31	-2.3015	L
R	1.75	-2	33	2.5371	L
R	1.75	-2	-20	-1.8907	N
S	1.75	6	10	1.5679	N
S	1.75	6	-20	-1.0178	N
T	1.75	-6	20	0.4178	N
T	1.75	-6	-10	-1.5276	N
U	2.00	0	31	2.6837	L
U	2.00	0	-25	-2.1323	L
V	2.00	2	10	1.1388	N
W	2.00	-2	10	0.6778	N
X	2.00	6	17	2.1917	L
Y	2.00	-6	10	0.2137	N

(1) CONDITION: L - LIMITING DEFLECTION
N - NON LIMITING DEFLECTION

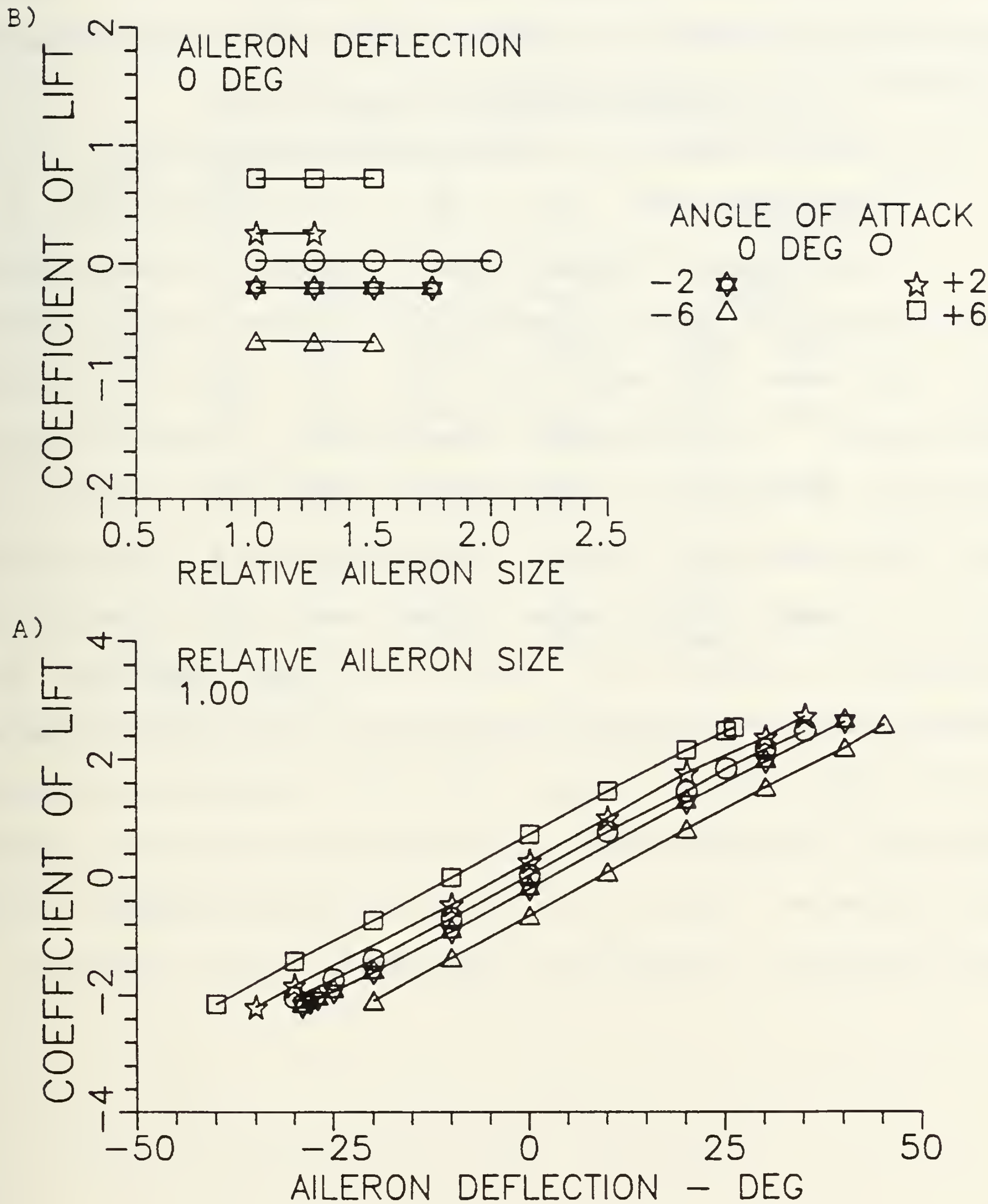

Figure 13
Effect of Varying the Angle of Attack

need not be a concern when implementing any changes to the aileron except for deflection angles in excess of 25°. Figure 13B shows the effect of increasing the angle of attack alone (without aileron deflection).

4. Combined Effect of Increased Aileron Size and Deflection

Combining the results of an increase in both aileron size and deflection would result in a larger rolling moment than has been discussed thus far for each individual improvement. As discussed previously, a total aileron deflection of ±25° is a reasonable modification. Table XI shows the resulting lift for ±25° deflection in combination with an increased aileron size. These results are graphically displayed in Figure 14. As can be seen, combining the increased deflection with an increased aileron chord creates a much larger rolling moment. For a 50% increase in aileron chord and 5 additional degrees of deflection there is almost a 60% increase. This is not quite the desired target but it does represent a significant improvement in roll response.

TABLE XI

EFFECT OF INCREASED AILERON SIZE AND DEFLECTION ON LIFT (1)

RELATIVE AILERON SIZE	AILERON DEFLECTION Deg	CL	AREA Ft^2	LIFT lb	INCREASE FROM BASELINE	(AVERAGE)
1.00	20	1.4839	166.56	32965.74	- BASELINE -	
1.00	20	-1.4095	166.56	-31312.90	- BASELINE -	
1.00	25	1.8294	166.56	40641.23	23.28%	23.53%
1.00	25	-1.7445	166.56	-38755.13	23.77%	
1.25	25	1.9483	178.01	46258.09	40.32%	40.92%
1.25	25	-1.8665	178.01	-44315.93	41.53%	
1.50	25	2.0448	189.46	51672.07	56.74%	58.26%
1.50	25	-1.9798	189.46	-50029.52	59.77%	
1.75	25	2.1239	200.91	56914.52	72.65%	74.61%
1.75	25	-2.0633	200.91	-55290.61	76.57%	
2.00	25	2.1975	212.36	62242.79	88.81%	90.84%
2.00	25	-2.1323	212.36	-60396.04	92.88%	

(1) ANGLE OF ATTACK = 0°

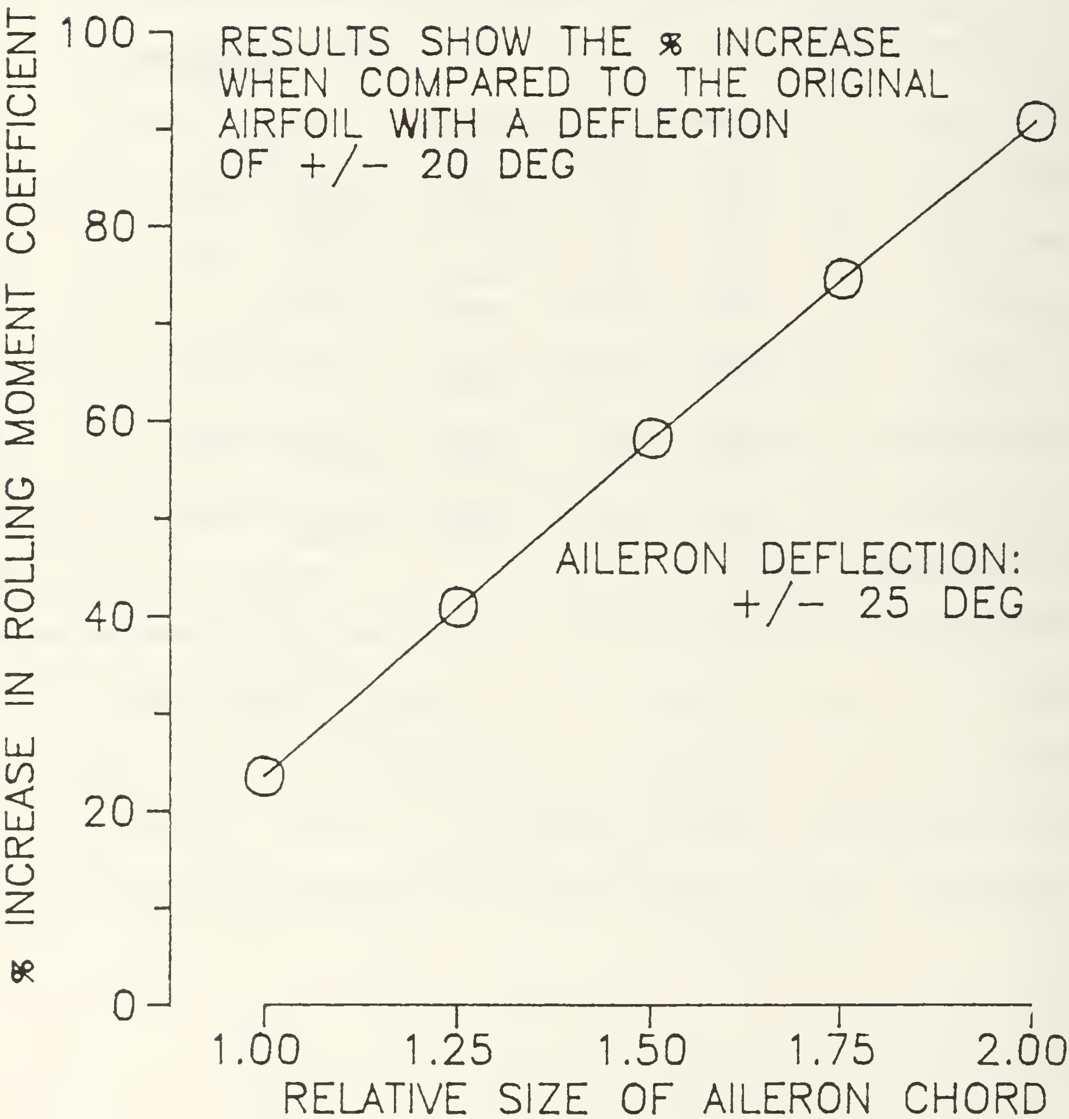

Figure 14
Effect of Increased Aileron
Size and Deflection

V. CONCLUSIONS

Tests were conducted on the P-3C OFT's at NAS Moffett Field to determine a realistic "target" for improvements to the lateral response characteristics of the P-3C aircraft. Doubling the current rolling moment coefficient of the aircraft was determined to be the goal. Several ways to achieve this goal have been discussed. Among these are:

(1) Reduce the control forces.

(2) Reduce the inherent delay of transmitting the control inputs to the control surfaces.

(3) Increase the total aileron deflection.

(4) Increase the aileron chord.

(5) Utilize the flaps for roll assist.

One method that was evaluated, but is not appropriate for consideration, is the utilization of asymmetric thrust for roll initiation.

A 2-D airfoil computer code was run to determine to what extent the current airfoil section of the P-3C wing would have to be altered to obtain the goal of doubling the value of C_l. It was found that by increasing the aileron deflection from an average of ±20° to ±25° and increasing the aileron chord by 50%, a 58% increase in C_l could be realized. Although this does not reach the goal of a 100% increase, it does provide for a significant increase in lateral control response. An increase in aileron size and deflection used in conjunction with some of the other suggested modifications would certainly approach the desired goal.

VI. RECOMMENDATIONS

Prior to incorporating any of the suggested modifications, it is recommended that an investigation of the structural impact on the airframe should be conducted. Additionally, further research should be conducted to determine the following:

(1) The feasibility of reducing the control forces.

(2) Ways of reducing the delays inherent in transmitting the control inputs to the control surfaces.

(3) The effect of adding spoilers and stall fences.

(4) The effect of using an active flap system.

(5) The optimal airfoil geometry for an increased aileron chord.

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APPENDIX A

TABLES

TABLE I

TESTS AND TEST CONDITIONS (PAGE 1 OF 4)

RUN NO.	PAGE NO.	AIRSPEED (KCAS)	PRESSURE ALTITUDE (FT)	MANEUVER DESCRIPTION	SIMULATOR CONDITION
1	101	196	517	0 TO 60 RT	BASELINE
1	102	195	524	0 TO 60 RT	BASELINE
2	103	202	545	0 TO 60 RT	BASELINE
2	104	201	553	0 TO 60 RT	BASELINE
2	105	199	583	0 TO 60 RT	BASELINE
3	106	200	516	0 TO 60 LT	BASELINE
3	107	199	512	0 TO 60 LT	BASELINE
3	108	200	491	0 TO 60 LT	BASELINE
4	109	244	500	60 RT TO 60 LT	BASELINE
4	110	245	500	60 RT TO 60 LT	BASELINE
4	111	243	500	60 RT TO 60 LT	BASELINE
4	112	238	500	60 RT TO 60 LT	BASELINE
5	113	202	500	60 LT TO 60 RT	BASELINE
6	114	210	500	0 TO 60 RT	K=.99
7	115	204	500	60 LT TO 60 RT	K=.99
8	116	268	500	0 TO 60 LT	K=.99
9	117	193	500	60 RT TO 60 LT	K=.99
10				HEADING CHANGES	K=.99
11	118	216	500	0 TO 60 RT	K=1.99
12	119	211	500	0 TO 60 LT	K=1.99
13		200	500	60 RT TO 60 LT	K=1.99
14		200	500	60 LT TO 60 RT	K=1.99
15	120	182	402	60 LT TO 60 RT	K=1.99
16				HEADING CHANGES	K=1.99
17	121	196	449	0 TO 60 LT	K=1.5
18	122	197	518	0 TO 60 RT	K=1.5
19	123	193	543	60 RT TO 60 LT	K=1.5
20	124	191	558	60 LT TO 60 RT	K=1.5
21				APPROACH	K=1.5
22	125	204	472	0 TO 60 RT	K=1.75
23	126	219	474	0 TO 60 LT	K=1.75
24	127	214	617	60 RT TO 60 LT	K=1.75
25	128	196	520	60 RT TO 60 LT	K=1.75
26	129	216	523	60 LT TO 60 RT	K=1.75
27				TAKE OFF AND LANDING	K=1.75
28	130	223	414	0 TO 60 RT	4 DEG DEFLECTION
29	131	218	355	0 TO 60 LT	4 DEG DEFLECTION
30	132	196	484	60 RT TO 60 LT	4 DEG DEFLECTION
31	133	192	701	60 LT TO 60 RT	4 DEG DEFLECTION
32		200	500	0 TO 60 RT	4 DEG DEFLECTION
33		200	500	0 TO 60 LT	4 DEG DEFLECTION
34		200	500	0 TO 60 RT	BASELINE
35		200	500	0 TO 60 LT	BASELINE

TABLE I

TESTS AND TEST CONDITIONS (PAGE 2 OF 4)

RUN NO.	PAGE NO.	AIRSPEED (KCAS)	PRESSURE ALTITUDE (FT)	MANEUVER DESCRIPTION	SIMULATOR CONDITION
36		200	500	60 RT TO 60 LT	BASELINE
37		200	500	60 LT TO 60 RT	BASELINE
38		200	500	90 DEG CW	BASELINE
39		200	500	30 DEG CCW	BASELINE
40		275	500	0 TO 60 RT	BASELINE
41		275	500	0 TO 60 LT	BASELINE
42		275	500	0 TO 60 LT	BASELINE
43		275	500	0 TO 60 RT	BASELINE
44		275	500	0 TO 60 RT	BASELINE
45		275	500	0 TO 60 LT	BASELINE
46		275	500	60 LT TO 60 RT	BASELINE
47		275	500	60 RT TO 60 LT	BASELINE
48		350	500	0 TO 60 RT	BASELINE
49		350	500	0 TO 60 RT	BASELINE
50		350	500	0 TO 60 LT	BASELINE
51		350	500	0 TO 60 LT	BASELINE
52		350	500	60 RT TO 60 LT	BASELINE
53		350	500	60 LT TO 60 RT	BASELINE
54		350	500	60 LT TO 60 RT	BASELINE
55		200	500	0 TO 60 RT	K=1.75
56		200	500	0 TO 60 RT	K=1.75
57		200	500	0 TO 60 RT	K=1.75
58	201	194	500	60 RT TO 60 LT	K=1.75
59	202	195	500	60 RT TO 60 LT	K=1.75
60	203	195	500	60 RT TO 60 LT	K=1.75
61	204	188	500	60 LT TO 60 RT	K=1.75
62	205	202	500	60 LT TO 60 RT	K=1.75
63	206	205	500	60 LT TO 60 RT	K=1.75
64	207	204	500	60 LT TO 60 RT	K=1.75
65		275	500	0 TO 60 RT	K=1.75
66		275	500	0 TO 60 RT	K=1.75
67		275	500	0 TO 60 RT	K=1.75
68		275	500	0 TO 60 LT	K=1.75
69		275	500	0 TO 60 LT	K=1.75
70		275	500	0 TO 60 LT	K=1.75
71	208	314	500	60 RT TO 60 LT	K=1.75
72	209	281	500	60 RT TO 60 LT	K=1.75
73	210	281	500	60 RT TO 60 LT	K=1.75
74	211	291	500	60 RT TO 60 LT	K=1.75
75	212	328	500	60 LT TO 60 RT	K=1.75
76	213	301	500	60 LT TO 60 RT	K=1.75
77	214	309	500	60 LT TO 60 RT	K=1.75
78	215	294	500	60 LT TO 60 RT	K=1.75

TABLE I

TESTS AND TEST CONDITIONS (PAGE 3 OF 4)

RUN NO.	PAGE NO.	AIRSPEED (KCAS)	PRESSURE ALTITUDE (FT)	MANEUVER DESCRIPTION	SIMULATOR CONDITION
79	216	282	500	60 LT TO 60 RT	K=1.75
80	217	257	500	60 LT TO 60 RT	K=1.75
81	218	263	500	60 LT TO 60 RT	K=1.75
82				APPROACH AND LANDING	K=1.75
83	219	170	10000	30 DEG CCW	BASELINE
84	220	178	10000	30 DEG CCW	BASELINE
85	221	177	10000	30 DEG CCW	BASELINE
86	222	175	10000	90 DEG CW	BASELINE
87	223	178	10000	90 DEG CW	BASELINE
88	224	181	10000	90 DEG CW	BASELINE
89	225	173	10089	ASYMMETRIC THRUST	BASELINE
90	226	184	10031	ASYMMETRIC THRUST	BASELINE
91		350	500	0 TO 60 RT	K=1.75
92		350	500	0 TO 60 RT	K=1.75
93		350	500	0 TO 60 LT	K=1.75
94		350	500	0 TO 60 LT	K=1.75
95	227	348	500	60 LT TO 60 RT	K=1.75
96	228	345	500	60 LT TO 60 RT	K=1.75
97	229	360	500	60 RT TO 60 LT	K=1.75
98	230	361	500	60 RT TO 60 LT	K=1.75
99	231	353	500	60 LT TO 60 RT	K=1.75
100	232	342	500	60 RT TO 60 LT	K=1.75
101	233	361	500	60 RT TO 60 LT	K=1.75
102	234	369	500	60 RT TO 60 LT	K=1.75
103			500	ASYMETRIC THRUST	K=1.75
104			500	ASYMETRIC THRUST	K=1.75
105	235	171	10000	90 DEG CW	K=1.75
106	236	172	10000	90 DEG CW	K=1.75
106	237	174	10000	90 DEG CW	K=1.75
107	238	168	10000	30 DEG CCW	K=1.75
108	239	171	10000	30 DEG CCW	K=1.75
109		200	500	0 TO 60 RT	8 DEG DEFLECTION
110		200	500	0 TO 60 RT	8 DEG DEFLECTION
111		200	500	0 TO 60 RT	8 DEG DEFLECTION
112		200	500	0 TO 60 RT	8 DEG DEFLECTION
113		200	500	0 TO 60 LT	8 DEG DEFLECTION
114		200	500	0 TO 60 LT	8 DEG DEFLECTION
115		200	500	0 TO 60 LT	8 DEG DEFLECTION
116		200	500	0 TO 60 LT	8 DEG DEFLECTION
117		200	500	0 TO 60 LT	8 DEG DEFLECTION
118		200	500	0 TO 60 RT	8 DEG DEFLECTION
119	240	247	500	60 RT TO 60 LT	8 DEG DEFLECTION
120	241	190	500	60 RT TO 60 LT	8 DEG DEFLECTION

TABLE I

TESTS AND TEST CONDITIONS (PAGE 4 OF 4)

RUN NO.	PAGE NO.	AIRSPEED (KCAS)	PRESSURE ALTITUDE (FT)	MANEUVER DESCRIPTION	SIMULATOR CONDITION
121	242	200	500	60 RT TO 60 LT	8 DEG DEFLECTION
122	243	204	500	60 LT TO 60 RT	8 DEG DEFLECTION
123	244	201	500	60 LT TO 60 RT	8 DEG DEFLECTION
124	245	203	500	60 LT TO 60 RT	8 DEG DEFLECTION
125	246	208	500	60 LT TO 60 RT	8 DEG DEFLECTION
126	247	284	500	60 RT TO 60 LT	8 DEG DEFLECTION
127	248	299	500	60 RT TO 60 LT	8 DEG DEFLECTION
128	249	287	500	60 RT TO 60 LT	8 DEG DEFLECTION
129	250	283	500	60 LT TO 60 RT	8 DEG DEFLECTION
130	251	308	500	60 LT TO 60 RT	8 DEG DEFLECTION
131	252	298	500	60 LT TO 60 RT	8 DEG DEFLECTION
132	253	279	500	60 LT TO 60 RT	8 DEG DEFLECTION
133		190	500	0 TO 60 LT	SPLIT FLAP
134		190	500	0 TO 60 LT	SPLIT FLAP
135		190	500	0 TO 60 LT	SPLIT FLAP
136		190	500	60 RT TO 60 LT	SPLIT FLAP
137		190	500	60 RT TO 60 LT	SPLIT FLAP
138		200	500	0 TO 60 LT	K=1.75
139		200	500	0 TO 60 LT	K=1.75
140		200	500	0 TO 60 LT	K=1.75

TABLE II

SUMMARY OF TEST RESULTS (PAGE 1 OF 5)

RUN NO.	PAGE NO.	BANK ANGLE (DEG)	ROLL VELOCITY (DEG/SEC)	ROLL ACCEL (DEG/SEC^2)	ROLLING MOMENT	AILERON POS (DEG)	WHEEL POS (DEG)	WHEEL FORCE (LBS)	STOP WATCH TIMES (SEC) STEADY 60 DEG	INITIAL 10 DEG	STEADY STATE ROLL RATE (DEG/SEC)
1	101	1.7	6.695	0.5364	431168	0.23	0.27	-4.45			
1	102	58.4	17.492	-0.0290	-17216	25.57	96.24	38.02			
2	103	-0.5	0.375	0.0180	15168	1.39	6.01	6.78	4.76		12.61
2	104	27.2	21.523	-0.0236	-29952	27.59	105.98	54.20			
2	105	66.6	16.898	-0.0066	4416	24.17	93.27	46.87			
3	106	0.0	-1.203	0.0028	2240	-0.29	-1.67	-8.33	3.52		17.05
3	107	-33.7	-24.586	0.0164	13568	-27.44	-105.02	-53.17			
3	108	-72.1	-1.094	0.4908	366592	10.64	42.18	24.03			
4	109	33.0	-21.336	0.0116	15232	-19.73	-83.51	-51.98			
4	110	-44.7	-18.406	0.0464	41344	-14.37	-60.91	-34.58			
4	111	-60.8	-16.172	-0.0669	-42624	-14.53	-62.48	-41.12			
4	112	-18.0	7.328	-0.2968	-226944	3.39	13.45	0.84			
5	113	-63.6	1.750	0.2357	263808	14.16	57.81	45.97			
6	114	24.2	24.344	-0.0331	-33728	23.02	89.87	38.11	2.95		20.34
7	115	-28.5	-25.492	-0.0408	-3592	-26.48	-102.56	-52.47	3.14	1.64	19.11
8	116	-39.5	-28.172	0.0124	12544	-18.71	-83.24	-65.62			
9	117	-31.1	-22.898	-0.0126	-1728	-22.59	-84.70	-31.61	2.58	1.53	23.26
11	118	15.8	42.172	0.5461	355584	24.34	97.22	47.61	0.58		103.45
12	119	-31.9	-48.523	-0.2970	-194752	-25.57	-100.73	-52.17	0.98		61.22
13									1.23		48.78
14										1.13	
15	120	-24.2	-43.602	-0.0149	-2816	-27.83	-101.56	-41.86	1.73	1.34	34.68
17	121	-41.9	-36.062	0.0494	39360	-23.03	-86.96	-32.19	2.71		22.14
18	122	22.3	34.430	0.1840	141440	28.56	108.73	56.19	2.42		24.79
19	123	36.5	29.711	0.0252	21184	26.34	99.55	47.53	1.92	1.10	31.25
20	124	-39.0	-34.359	-0.0447	-34560	-27.81	-104.59	-53.80	2.05	1.17	29.27
22	125	15.5	37.180	0.2947	227008	24.61	94.50	36.70	2.43		24.69
23	126	-19.9	-42.664	-0.3396	-260992	-24.45	-98.92	-58.11	2.21		27.15
24	127	38.4	45.937	0.0090	6720	24.52	96.91	46.08	2.08		28.85

TABLE II

SUMMARY OF TEST RESULTS (PAGE 2 OF 5)

RUN NO.	PAGE NO.	BANK ANGLE (DEG)	ROLL VELOCITY (DEG/SEC)	ROLL ACCEL (DEG/SEC^2)	ROLLING MOMENT	AILERON POS (DEG)	WHEEL POS (DEG)	WHEEL FORCE (LBS)	STOP WATCH TIMES (SEC) STEADY 60 DEG	INITIAL 10 DEG	STEADY STATE ROLL RATE (DEG/SEC)
25	128	-30.2	-40.195	-0.0495	38400	-26.34	-99.68	-44.75	1.78	1.26	33.71
26	129	31.7	36.797	-0.0030	-5376	25.43	101.35	54.72	1.51	1.03	39.74
28	130	15.9	22.766	0.1064	82048	25.86	105.89	66.70	3.40		17.65
29	131	-58.1	-24.930	0.0014	0	-25.64	-102.95	-59.11	3.24		18.52
30	132	-39.9	-24.219	-0.0461	-34816	-25.88	-99.05	-51.48	2.76	1.32	21.74
31	133	27.4	19.477	-0.0092	-5056	29.00	109.35	54.30	3.00	1.18	20.00
32									2.59		23.17
33									3.19		18.81
34									4.19		14.32
35									3.83		15.67
36										1.57	
37									3.09	1.59	19.42
40									3.72		16.13
41									3.69		16.26
42									3.50		17.14
43									3.54		16.95
44									3.54		16.95
45									3.63		16.53
46									2.99	1.52	20.07
47									3.37	1.58	17.80
48									4.11		14.60
49									3.85		15.58
50									3.46		17.34
51									3.25		18.46
52									2.94	1.70	20.41
53										1.45	
54									3.89	1.15	15.42
55									2.44		24.59
56									2.56		23.44

TABLE II

SUMMARY OF TEST RESULTS (PAGE 3 OF 5)

RUN NO.	PAGE NO.	BANK ANGLE (DEG)	ROLL VELOCITY (DEG/SEC)	ROLL ACCEL (DEG/SEC^2)	ROLLING MOMENT	AILERON POS (DEG)	WHEEL POS (DEG)	WHEEL FORCE (LBS)	STOP WATCH TIMES (SEC) STEADY 60 DEG	INITIAL 10 DEG	STEADY STATE ROLL RATE (DEG/SEC)
57									2.00		30.00
58	201	-60.8	-42.695	0.0600	47488	-22.66	-85.16	-31.23	1.63	1.19	36.81
59	202	-53.9	-42.969	-0.0270	-19712	-26.59	-100.09	-43.48	1.67	1.59	35.93
60	203	-64.8	-41.516	-0.0290	1536	-23.61	-97.67	-40.48	1.63	0.99	36.81
61	204	53.2	41.148	0.1034	75520	26.89	99.61	40.91	1.57	1.21	38.22
62	205	42.2	46.031	-0.0269	-23296	26.27	101.05	47.31	1.33	1.08	45.11
63	206	61.6	46.344	-0.0287	-24000	23.31	89.48	29.69	1.45	1.05	41.38
64	207	61.7	45.914	-0.0349	-27968	24.49	94.48	40.02	1.53	1.39	39.22
65									2.34		25.64
66									1.93		31.09
67									2.13		28.17
68									2.32		25.86
69									1.89		31.75
70									2.19		27.40
71	208	-41.7	-44.711	0.0854	69440	-15.94	-76.42	-72.72	1.65	0.99	36.36
72	209	-92.4	-44.437	0.5361	1920	-7.98	-28.50	49.16	1.42	1.01	42.25
73	210	-53.6	-48.625	0.0042	4864	-17.81	-80.70	-65.94	1.30	1.14	46.15
74	211	-86.7	-43.125	0.0600	46848	-14.21	-65.06	-50.12	1.44	1.30	41.67
75	212	41.2	37.953	0.0117	6720	14.08	71.15	85.08	1.95	1.09	30.77
76	213	69.1	30.719	-1.5165	-112704	-1.62	-11.59	-49.41		1.14	
77	214	42.2	37.070	-0.0030	-5440	14.06	67.20	63.69	1.77	1.12	33.90
78	215	-45.5							1.13	1.13	53.10
79	216	63.1							1.23	1.05	48.78
80	217	42.7	46.242	-0.0771	-61888	19.46	84.38	57.23	1.67	1.03	35.93
81	218	88.3	38.367	-0.2099	-230016	14.16	61.36	30.25	1.20	0.98	50.00
83	219	-65.1	-8.930	0.0115	4288	-7.58	-26.05	5.97			
84	220	-27.8	-7.992	0.0021	1920	-8.32	-30.72	-12.52			
85	221	-28.0	-9.141	0.0132	10816	-9.67	-34.86	-8.80			

TABLE II

SUMMARY OF TEST RESULTS (PAGE 4 OF 5)

RUN NO.	PAGE NO.	BANK ANGLE (DEG)	ROLL VELOCITY (DEG/SEC)	ROLL ACCEL (DEG/SEC^2)	ROLLING MOMENT	AILERON POS (DEG)	WHEEL POS (DEG)	WHEEL FORCE (LBS)	STOP WATCH TIMES (SEC) STEADY 60 DEG	STOP WATCH TIMES (SEC) INITIAL 10 DEG	STEADY STATE ROLL RATE (DEG/SEC)
86	222	73.3	6.297	-1.0822	-34560	-29.93	-108.26	-53.52			
87	223	44.5	25.031	-0.0098	-1688	29.07	104.72	43.08			
88	224	56.8	23.937	-0.0144	-11456	27.52	100.41	41.95			
89	225	74.0	20.320	-0.6795	-51248	-15.86	-59.27	-29.95			
90	226	70.8	34.937	-0.1327	-93440	12.36	41.12	-24.73			
91									2.63		22.81
92									2.58		23.26
93									2.59		23.17
94									2.60		23.08
95	227	30.5	32.594	-0.0525	-41536	10.46	54.27	64.89	1.91	1.11	31.41
96	228	79.1	40.391	0.0237	17856	13.22	67.92	79.39	1.74	1.14	34.48
97	229	-67.9	-34.805	0.0019	2432	-10.98	-57.91	-69.45	2.09	1.41	28.71
98	230	-49.7	-35.859	0.0092	9024	-11.25	-59.94	-76.77	1.81	1.15	33.15
99	231	34.7	34.602	-0.0487	-4128	11.27	59.04	72.41	1.69	1.38	35.50
100	232	-64.9	-39.789	-0.0259	-18944	-11.99	-61.07	-68.27	1.50	1.45	40.00
101	233	-28.3	-35.859	-0.0846	-62784	-11.32	-61.28	-84.72	1.89	1.09	31.75
102	234	-22.2	-25.922	-0.0132	8320	-7.89	-43.47	-61.95	2.47		24.29
103									2.38		25.21
104									2.47		24.29
105	235	113.8	40.742	-0.9120	-39424	30.89	108.80	43.81			
106	236	3.2	1.789	0.0030	2432	1.08	3.77	0.34			
106	237	107.1	45.000	-0.1105	-79808	26.88	95.58	25.50			
107	238	-35.3	-16.984	0.0273	22400	-9.69	-34.06	-6.34			
108	239	-37.7	-14.430	0.0777	59968	-7.30	-25.80	-5.12			
109									3.21		18.69
110									3.19		18.81
111									3.33		18.02
112									3.37		17.80
113									3.25		18.46

TABLE II

SUMMARY OF TEST RESULTS (PAGE 5 OF 5)

RUN NO.	PAGE NO.	BANK ANGLE (DEG)	ROLL VELOCITY (DEG/SEC)	ROLL ACCEL (DEG/SEC^2)	ROLLING MOMENT	AILERON POS (DEG)	WHEEL POS (DEG)	WHEEL FORCE (LBS)	STOP WATCH TIMES (SEC) STEADY 60 DEG	STOP WATCH TIMES (SEC) INITIAL 10 DEG	STEADY STATE ROLL RATE (DEG/SEC)
114									3.29		18.24
115									3.33		18.02
116									3.52		17.05
117									3.49		17.19
118									3.56		16.85
119	240	-37.2	-22.867	-0.0155	-12544	-19.39	-82.45	-50.69	2.84	1.33	21.13
120	241	-50.4	-24.922	0.0621	42048	-26.17	-98.42	-46.50	2.83	1.57	21.20
121	242	-47.5	-24.969	0.0239	11712	-25.65	-97.98	-44.06	2.68	1.58	22.39
122	243	48.2	21.453	-0.0246	-21952	19.48	75.33	30.59	2.96	1.91	20.27
123	244	47.3	14.242	-0.2101	-154176	10.41	40.78	21.94	3.25	1.70	18.46
124	245	45.2	26.984	-0.0387	-26496	27.11	104.87	55.72	2.84	1.47	21.13
125	246	42.0	22.344	0.0000	640	25.56	101.16	60.84	2.92	1.88	20.55
126	247	-52.8	-30.625	-0.0252	-17856	-18.93	-86.01	-70.05	2.03	1.34	29.56
127	248	-80.5	-16.250	0.6794	519040	-2.03	-7.94	5.02	2.62	1.44	22.90
128	249	-81.1	15.937	0.5872	445568	16.39	75.98	65.05	2.27	1.63	26.43
129	250	24.0	17.312	-0.0585	-48000	12.08	55.52	48.34	3.70	1.26	16.22
130	251	39.1	18.844	0.0122	6976	13.59	64.87	60.95	3.41	1.52	17.60
131	252	49.4	22.781	0.0117	9600	16.56	78.83	80.94	2.91		20.62
132	253	48.9	27.039	0.0216	15488	18.79	84.76	67.56	2.50	1.32	24.00
133									2.51		23.90
134									2.75		21.82
135									2.87		20.91
136									2.13	1.12	28.17
137									2.01	1.20	29.85
138									2.23		26.91
139									2.19		27.40
140									2.35		25.53

TABLE III

SUMMARY OF EFFECTS OF CHANGING THE AILERON ROLLING MOMENT COEFFICIENT (PAGE 1 OF 2)

RUN NO.	PAGE NO.	KCAS	PRESSURE ALTITUDE (FT)	MANEUVER DESCRIPTION	K	BANK ANGLE (DEG)	ROLL VELOCITY (DEG/SEC)	ROLL ACCEL (DEG/S/S)	ROLLING MOMENT	AILERON POS (DEG)	WHEEL POS (DEG)	WHEEL FORCE (LB)	STOP WATCH TIMES (SEC) STEADY 60 DEG	STOP WATCH TIMES (SEC) INITIAL TEN DEG	STEADY STATE ROLL RATE (DEG/SEC)
8	116	268	500	0 TO 60 LT	0.99	-39.5	-28.172	0.0124	12544	-18.71	-83.24	-65.62			
6	114	210	500	0 TO 60 RT	0.99	24.2	24.344	-0.0331	-33728	23.02	89.87	38.11	2.95		20.34
7	115	204	500	60 LT TO 60 RT	0.99	-28.5	-25.492	-0.0408	-3592	-26.48	-102.56	-52.47	3.14	1.64	19.11
9	117	193	500	60 RT TO 60 LT	0.99	-31.1	-22.898	-0.0126	-1728	-22.59	-84.70	-31.61	2.58	1.53	23.26
10				HEADING CHANGES	0.99										
17	121	196	449	0 TO 60 LT	1.50	-41.9	-36.062	0.0494	39360	-23.03	-86.96	-32.19	2.71		22.14
18	122	197	518	0 TO 60 RT	1.50	22.3	34.430	0.1840	141440	28.56	108.73	56.19	2.42		24.79
20	124	191	558	60 LT TO 60 RT	1.50	-39.0	-34.359	-0.0447	-34560	-27.81	-104.59	-53.80	2.05	1.17	29.27
19	123	193	543	60 RT TO 60 LT	1.50	36.5	29.711	0.0252	21184	26.34	99.55	47.53	1.92	1.10	31.25
21				APPROACH	1.50										
138		200	500	0 TO 60 LT	1.75								2.23		26.91
139		200	500	0 TO 60 LT	1.75								2.19		27.40
140		200	500	0 TO 60 LT	1.75								2.35		25.53
23	126	219	474	0 TO 60 LT	1.75	-19.9	-42.664	-0.3396	-260992	-24.45	-98.92	-58.11	2.21		27.15
68		275	500	0 TO 60 LT	1.75								2.32		25.86
69		275	500	0 TO 60 LT	1.75								1.89		31.75
70		275	500	0 TO 60 LT	1.75								2.19		27.40
93		350	500	0 TO 60 LT	1.75								2.59		23.17
94		350	500	0 TO 60 LT	1.75								2.60		23.08
55		200	500	0 TO 60 RT	1.75								2.44		24.59
56		200	500	0 TO 60 RT	1.75								2.56		23.44
57		200	500	0 TO 60 RT	1.75								2.00		30.00
22	125	204	472	0 TO 60 RT	1.75	15.5	37.180	0.2947	227008	24.61	94.50	36.70	2.43		24.69
65		275	500	0 TO 60 RT	1.75								2.34		25.64
66		275	500	0 TO 60 RT	1.75								1.93		31.09
67		275	500	0 TO 60 RT	1.75								2.13		28.17
91		350	500	0 TO 60 RT	1.75								2.63		22.81
92		350	500	0 TO 60 RT	1.75								2.58		23.26
61	204	188	500	60 LT TO 60 RT	1.75	53.2	41.148	0.1034	75520	26.89	99.61	40.91	1.57	1.21	38.22
62	205	202	500	60 LT TO 60 RT	1.75	42.2	46.031	-0.0269	-23296	26.27	101.05	47.31	1.33	1.08	45.11
64	207	204	500	60 LT TO 60 RT	1.75	61.7	45.914	-0.0349	-27968	24.49	94.48	40.02	1.53	1.39	39.22
63	206	205	500	60 LT TO 60 RT	1.75	61.6	46.344	-0.0287	-24000	23.31	89.48	29.69	1.45	1.05	41.38
26	129	216	523	60 LT TO 60 RT	1.75	31.7	36.797	-0.0030	-5376	25.43	101.35	54.72	1.51	1.03	39.74
80	217	257	500	60 LT TO 60 RT	1.75	42.7	46.242	-0.0771	-61888	19.46	84.38	57.23	1.67	1.03	35.93
81	218	263	500	60 LT TO 60 RT	1.75	88.3	38.367	-0.2099	-230016	14.16	61.36	30.25	1.20	0.98	50.00
79	216	282	500	60 LT TO 60 RT	1.75	63.1							1.23	1.05	48.78
78	215	294	500	60 LT TO 60 RT	1.75	-45.5							1.13	1.13	53.10

TABLE III

SUMMARY OF EFFECTS OF CHANGING THE AILERON ROLLING MOMENT COEFFICIENT (PAGE 2 OF 2)

RUN NO.	PAGE NO.	KCAS	PRESSURE ALTITUDE (FT)	MANEUVER DESCRIPTION	K	BANK ANGLE (DEG)	ROLL VELOCITY (DEG/SEC)	ROLL ACCEL (DEG/S/S)	ROLLING MOMENT	AILERON POS (DEG)	WHEEL POS (DEG)	WHEEL FORCE (LB)	STOP WATCH TIMES (SEC) STEADY 60 DEG	STOP WATCH TIMES (SEC) INITIAL TEN DEG	STEADY STATE ROLL RATE (DEG/SEC)
76	213	301	500	60 LT TO 60 RT	1.75	69.1	30.719	-1.5165	-112704	-1.62	-11.59	-49.41		1.14	
77	214	309	500	60 LT TO 60 RT	1.75	42.2	37.070	-0.0030	-5440	14.06	67.20	63.69	1.77	1.12	33.90
75	212	328	500	60 LT TO 60 RT	1.75	41.2	37.953	0.0117	6720	14.08	71.15	85.08	1.95	1.09	30.77
96	228	345	500	60 LT TO 60 RT	1.75	79.1	40.391	0.0237	17856	13.22	67.92	79.39	1.74	1.14	34.48
95	227	348	500	60 LT TO 60 RT	1.75	30.5	32.594	-0.0525	-41536	10.46	54.27	64.89	1.91	1.11	31.41
99	231	353	500	60 LT TO 60 RT	1.75	34.7	34.602	-0.0487	-4128	11.27	59.04	72.41	1.69	1.38	35.50
58	201	194	500	60 RT TO 60 LT	1.75	-60.8	-42.695	0.0600	47488	-22.66	-85.16	-31.23	1.63	1.19	36.81
59	202	195	500	60 RT TO 60 LT	1.75	-53.9	-42.969	-0.0270	-19712	-26.59	-100.09	-43.48	1.67	1.59	35.93
60	203	195	500	60 RT TO 60 LT	1.75	-64.8	-41.516	-0.0290	1536	-23.61	-97.67	-40.48	1.63	0.99	36.81
25	128	196	520	60 RT TO 60 LT	1.75	-30.2	-40.195	-0.0495	38400	-26.34	-99.68	-44.75	1.78	1.26	33.71
24	127	214	617	60 RT TO 60 LT	1.75	38.4	45.937	0.0090	6720	24.52	96.91	46.08	2.08		28.85
72	209	281	500	60 RT TO 60 LT	1.75	-92.4	-44.437	0.5361	1920	-7.98	-28.50	49.16	1.42	1.01	42.25
73	210	281	500	60 RT TO 60 LT	1.75	-53.6	-48.625	0.0042	4864	-17.81	-80.70	-65.94	1.30	1.14	46.15
74	211	291	500	60 RT TO 60 LT	1.75	-86.7	-43.125	0.0600	46848	-14.21	-65.06	-50.12	1.44	1.30	41.67
71	208	314	500	60 RT TO 60 LT	1.75	-41.7	-44.711	0.0854	69440	-15.94	-76.42	-72.72	1.65	0.99	36.36
100	232	342	500	60 RT TO 60 LT	1.75	-64.9	-39.789	-0.0259	-18944	-11.99	-61.07	-68.27	1.50	1.45	40.00
97	229	360	500	60 RT TO 60 LT	1.75	-67.9	-34.805	0.0019	2432	-10.98	-57.91	-69.45	2.09	1.41	28.71
98	230	361	500	60 RT TO 60 LT	1.75	-49.7	-35.859	0.0092	9024	-11.25	-59.94	-76.77	1.81	1.15	33.15
101	233	361	500	60 RT TO 60 LT	1.75	-28.3	-35.859	-0.0846	-62784	-11.32	-61.28	-84.72	1.89	1.09	31.75
102	234	369	500	60 RT TO 60 LT	1.75	-22.2	-25.922	-0.0132	8320	-7.89	-43.47	-61.95	2.47		24.29
107	238	168	10000	30 DEG CCW	1.75	-35.3	-16.984	0.0273	22400	-9.69	-34.06	-6.34			
108	239	171	10000	30 DEG CCW	1.75	-37.7	-14.430	0.0777	59968	-7.30	-25.80	-5.12			
105	235	171	10000	90 DEG CW	1.75	113.8	40.742	-0.9120	-39424	30.89	108.80	43.81			
106	237	174	10000	90 DEG CW	1.75	107.1	45.000	-0.1105	-79808	26.88	95.58	25.50			
27			617	TAKE OFF/LANDING	1.75										
82			500	APPROACH/LANDING	1.75										
103			500	ASYMETRIC THRUST	1.75								2.38		25.21
104			500	ASYMETRIC THRUST	1.75								2.47		24.29
12	119	211	500	0 TO 60 LT	1.99	-31.9	-48.523	-0.2970	-194752	-25.57	-100.73	-52.17	0.98		61.22
11	118	216	500	0 TO 60 RT	1.99	15.8	42.172	0.5461	355584	24.34	97.22	47.61	0.58		103.45
15	120	182	402	60 LT TO 60 RT	1.99	-24.2	-43.602	-0.0149	-2816	-27.83	-101.56	-41.86	1.73	1.34	34.68
14		200	500	60 LT TO 60 RT	1.99									1.13	
13		200	500	60 RT TO 60 LT	1.99								1.23		48.78

APPENDIX B

PROGRAM LISTING: WINGIT

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C  THIS PROGRAM IS DESIGNED TO CONVERT ANY SPECIFIC AIRFOIL
C  INTO ANY OTHER AIRFOIL OF THE SAME FAMILY.  IT CAN CHANGE
C  THE THICKNESS AS WELL AS THE AILERON SIZE AND DEFLECTION.
C
C               COORDINATE TRANSFORMATION PROGRAM
C
C  THIS SECTION TAKES A GIVEN INPUT FILE FOR SEARCHSE AND CONVERTS IT
C  TO ANOTHER INPUT FILE FOR SEARCHSE WITH A DIFFERENT THICKNESS AIRFOIL
            COMMON/SUBS/RX(200),R2(200),ARX(200),ARZ(200)
            CHARACTER FLNAM*20
            CHARACTER TITLE*80
            CHARACTER FNEW*20
            CHARACTER THK,AS,DA
            WRITE(*,300)
 300        FORMAT('ENTER THE DATA FILE THAT CONTAINS YOUR DATA')
            READ(*,101) FLNAM
 101        FORMAT(A20)
            WRITE(*,*) 'INPUT NEW DATA TITLE'
            READ(*,104) FNEW
            OPEN(UNIT=4,FILE=FLNAM,STATUS='OLD')
            OPEN(UNIT=7,FILE=FNEW,STATUS='NEW')
            READ(4,102) TITLE
 104        FORMAT(A20)
            READ(4,*) NALPHA
            READ(4,*) ALPHA
            READ(4,*) NOE,MODE
            READ(4,*) AMINF,PO,TO,CREF,VKO,DAMP
            READ(4,*) NIPI
            READ(4,*) (RX(N),RZ(N),N=1,NIPI)
            READ(4,*) SFACT
            READ(4,*) HMAX
            READ(4,*) GAPMIN
            READ(4,*) KCAS,NTRAL,NTRAU,ITSEPU
            WRITE(*,*) 'ENTER X/C LOCATION OF THE AILERON PIVOT'
            READ(*,*) XAP
            WRITE(*,*) 'ENTER WING CHORD LENGTH IN FEET'
            READ(*,*) WC
            WRITE(*,*) 'DO YOU WANT TO CHANGE THICKNESS? (Y OR N)'
            READ '(A)',THK
            IF (THK.EQ.'N') GO TO 700
            WRITE(*,*) 'ENTER THE THICKNESS OF THE NEW WING STATION'
            READ(*,*) WST
            WRITE(*,*) 'ENTER ORIGINAL WING STATION THICKNESS'
            READ(*,*) WSTO
            CALL THICK(WST,NIPI,WSTO)
 700        CONTINUE
C
C  THIS SECTION WIL CHANGE THE RELATIVE AILERON CHORD LENGTH
C  THEN NONDIMENSIONALIZE THE COORDINATES WITH RESPECT TO THE
C  NEW TOTAL AIRFOIL CHORD LENGTH
C
            WRITE(*,*) 'DO YOU WANT TO CHANGE AILERON SIZING? (Y OR N)'
            READ '(A)',AS
            IF (AS.EQ.'N') GO TO 800
            WRITE(*,*) 'BY WHAT FACTOR DO YOU WANT TO CHANGE AILERON CHORD?'
            WRITE(*,*) 'I.E. A FACTOE OF 2 WILL DOUBLE THE AILERON CHORD'
            READ(*,*) AILF
```

```
          CALL INCAIL(NIPI,XAP,AILF)
C
C  THIS SECTION WILL DEFLECT THE AILERON IN EITHER A POSITIVE (DOWNWARD)
C  OR NEGATIVE (UPWARD) DIRECTION
C
 800      WRITE (*,*) 'DO YOU WANT TO DEFLECT THE AILERON (Y OR N)'
          READ'(A)',DA
          IF (DA.EQ.'N') GOTO 200
 850      WRITE (*,*) 'ENTER AILERON DEFLECTION ANGLE'
          READ (*,*) DELA
          IF (DELA.EQ.0.0) GO TO 200
          CALL AILDEF(DELA,NIPI,XAP,AC,WC)
C
C  THIS SECTION WRITES THE NEW DATA TO THE NEW DATA FILE
C  THIS FILE WILL BE IN A FORM RECOGNIZEABLE TO SEARCHSE
C
 200      CONTINUE
          WRITE(7,111) FNEW
          WRITE(7,112) NALPHA
          WRITE(7,113) ALPHA
          WRITE(7,114) NOE,MODE
          WRITE(7,115) AMINF,PO,TO,WC,VKO,DAMP
          WRITE(7,116) NIPI
          WRITE(7,117) (RX(N),RZ(N),N=1,NIPI)
          WRITE(7,118) SFACT
          WRITE(7,119) HMAX
          WRITE(7,120) GAPMIN
          WRITE(7,121) KCAS,NTRAL,NTRAU,ITSEPU
 111      FORMAT (20A6)
 112      FORMAT (I5)
 113      FORMAT (F10.1)
 114      FORMAT (2I5)
 115      FORMAT (10.2,F10.2,F10.1,F10.2,F10.6,F10.2)
 116      FORMAT (I5)
 117      FORMAT (2F10.5)
 118      FORMAT (F10.1)
 119      FORMAT (F10.2)
 120      FORMAT (F10.3)
 121      FORMAT (4I5)
 102      FORMAT (A50)
C
          END
C
                          SUBROUTINE THICK(WST,NIPI,WSTO)
          COMMON/SUBS/RX(200),RZ(200)
          DO 100 I=1,NIPI
          RZ(I)=RZ(I)*WST/WSTO
 100      CONTINUE
          RETURN
          END
C
                          SUBROUTINE AILDEF(DELA,NIPI,XAP,AC,WC)
C
          COMMON/SUBS/RX(200),RZ(200),ARX(200),ARZ(200)
          DEL=DELA*3.14159/180.0
          ANG=90.0**3.14159/180.0
          K=0
          DO 200 I=1,NIPI
          J=I-K
          IF(RX(I).LT.XAP) GO TO 300
          RADX=RX(I)-XAP
```

```
      R=SPRT(RADX**2+RZ(I)**2)
      THETA=ATAN(RZ(I)/RADX)
      THETAN=THETA-DEL
      IF(ABS(THETAN).GT.ANG)THEN
      K=K+1
      GO TO 200
      ENDIF
      RX(I)=XAP+R*COS(THETAN)
      RZ(I)=R*SIN(THETAN)
 300  CONTINUE
      ARX(J)=RX(I)
      ARZ(J)=RZ(I)
 200  CONTINUE
      NIPI=NIPI-K
      DO 400 I=1,NIPI
      RX(I)=ARX(I)
      RZ(I)=ARZ(I)
 400  CONTINUE
      RETURN
      END
C
                  SUBROUTINE INCAIL(NIPI,XAP,AILF)
C
      COMMON/SUBS/RX(200),RZ(200)
      DO 500 I=1,NIPI
      RX(I)=(RX(I)-XAP)*AILF)+XAP
 500  CONTINUE
      DO 600 I=1,NIPI
      RX(I)=((RX(I))/(XAP+(AILF*91-XAP)))
 600  CONTINUE
      XAP=XAP/(XAP+(AILF*(1-XAP)))
      RETURN
      END
```

APPENDIX C

FIGURES
(AIRFOIL CODE DATA SUMMARY)

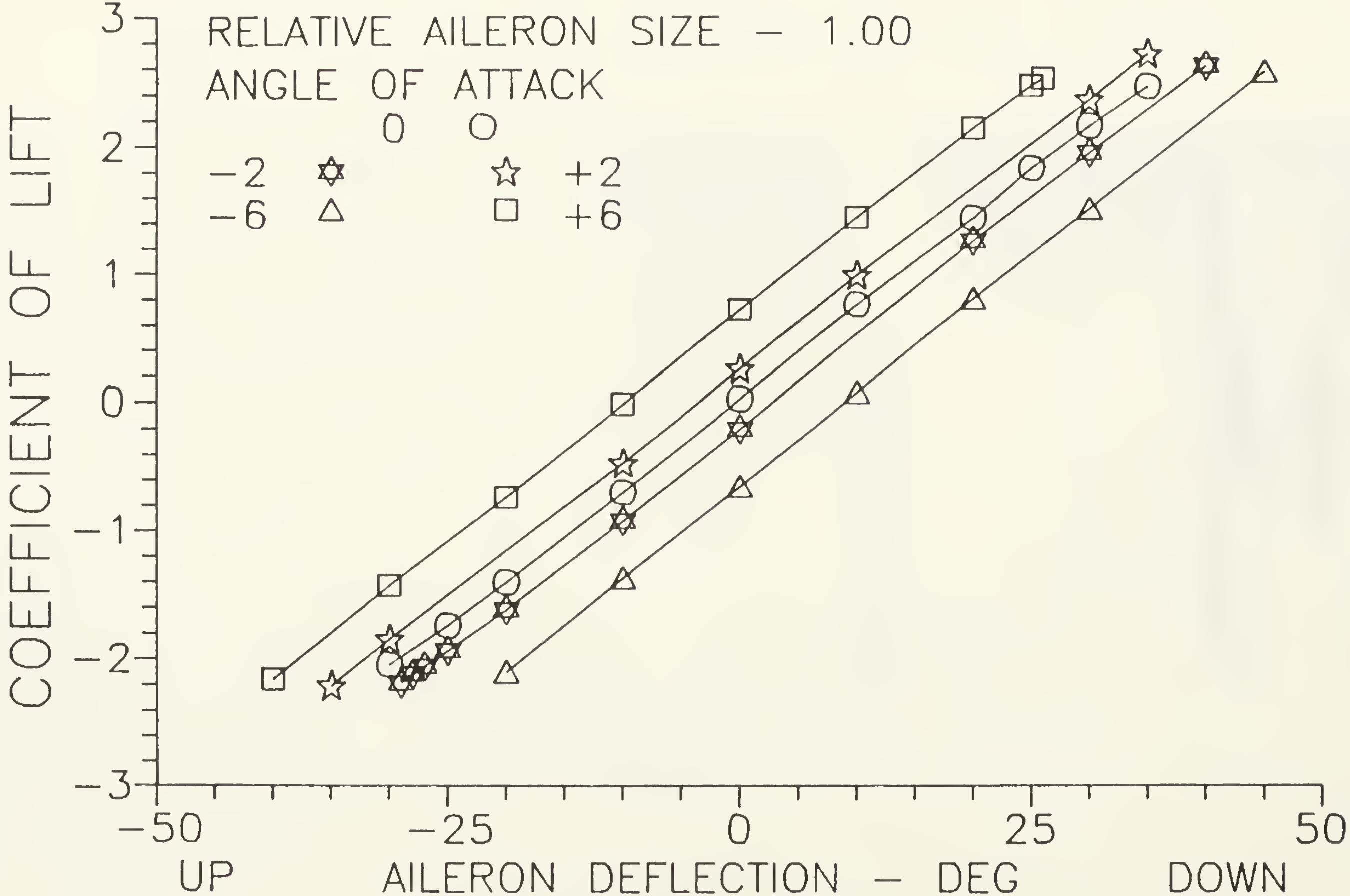

Figure 1
Effect of Aileron Deflection Angle

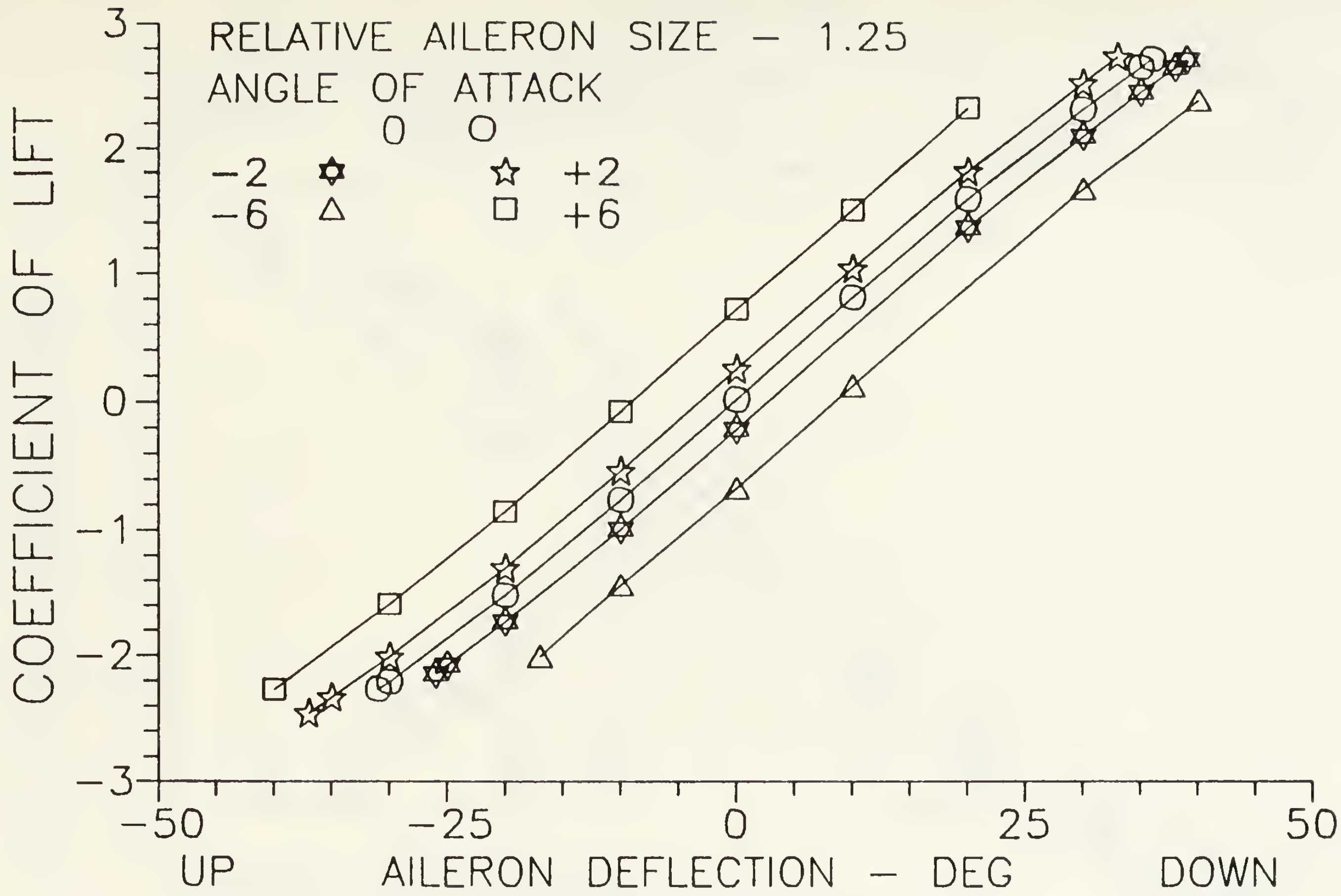

Figure 2
Effect of Aileron Deflection Angle

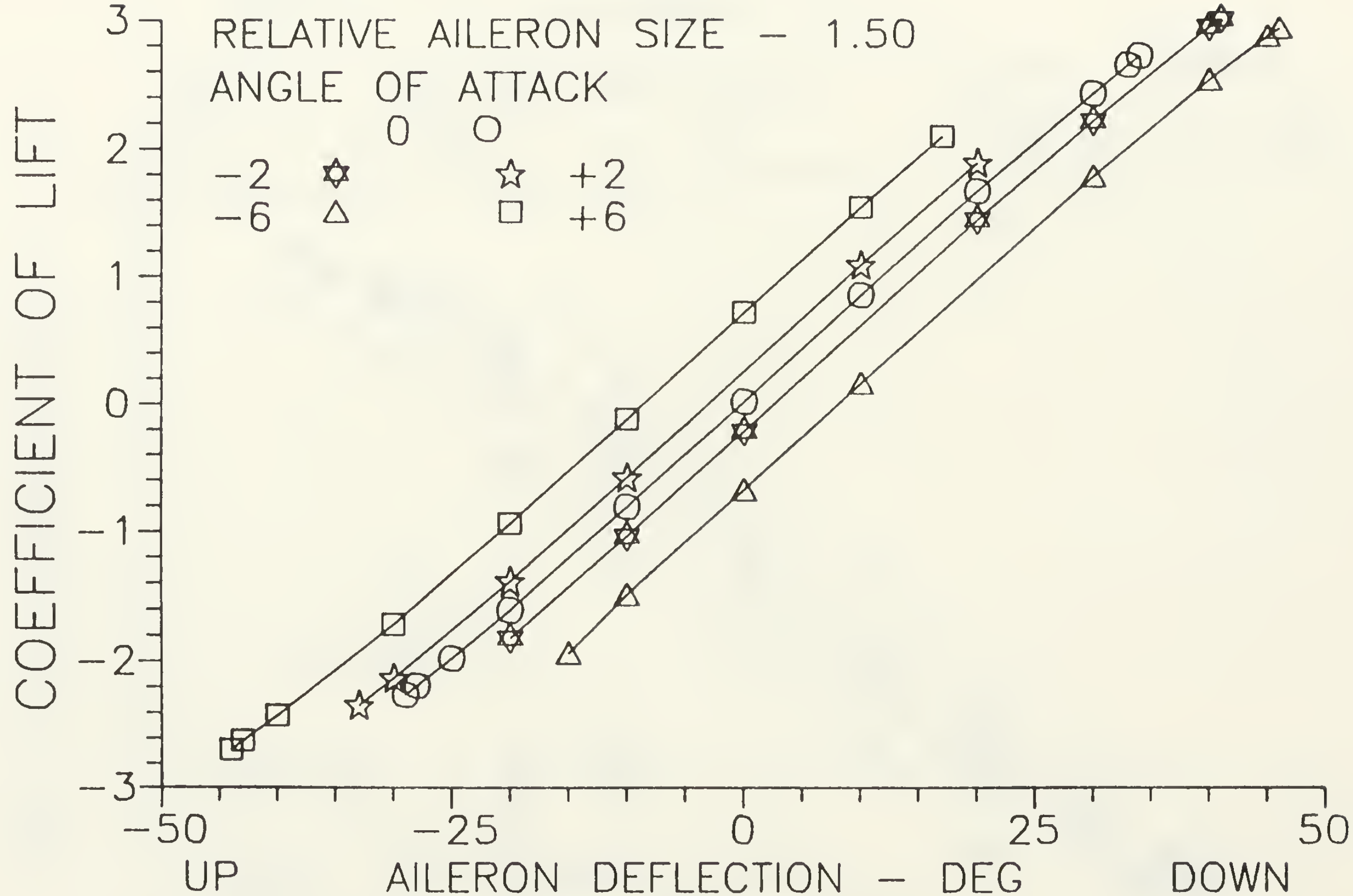

Figure 3
Effect of Aileron Deflection Angle

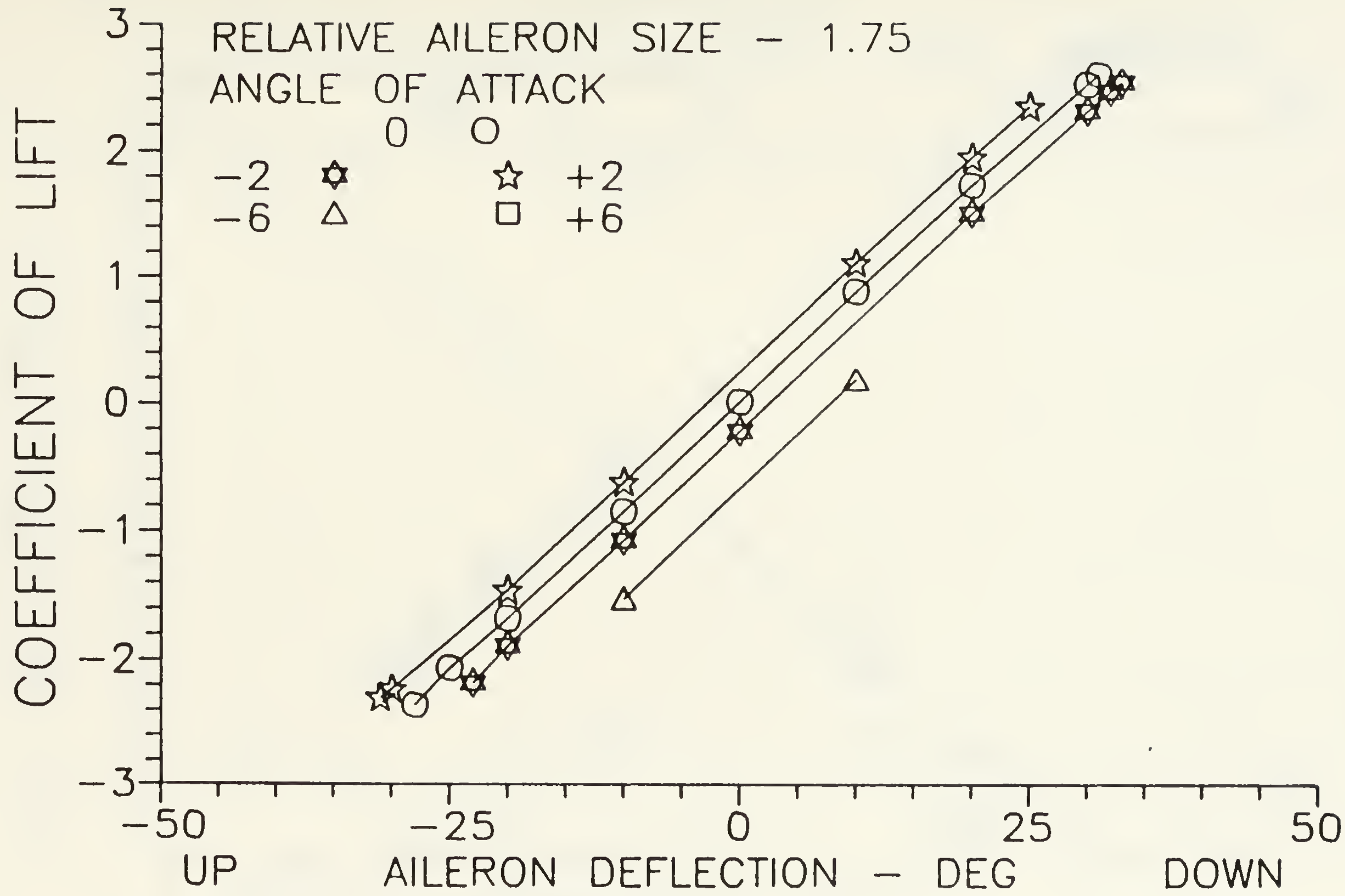

Figure 4
Effect of Aileron Deflection Angle

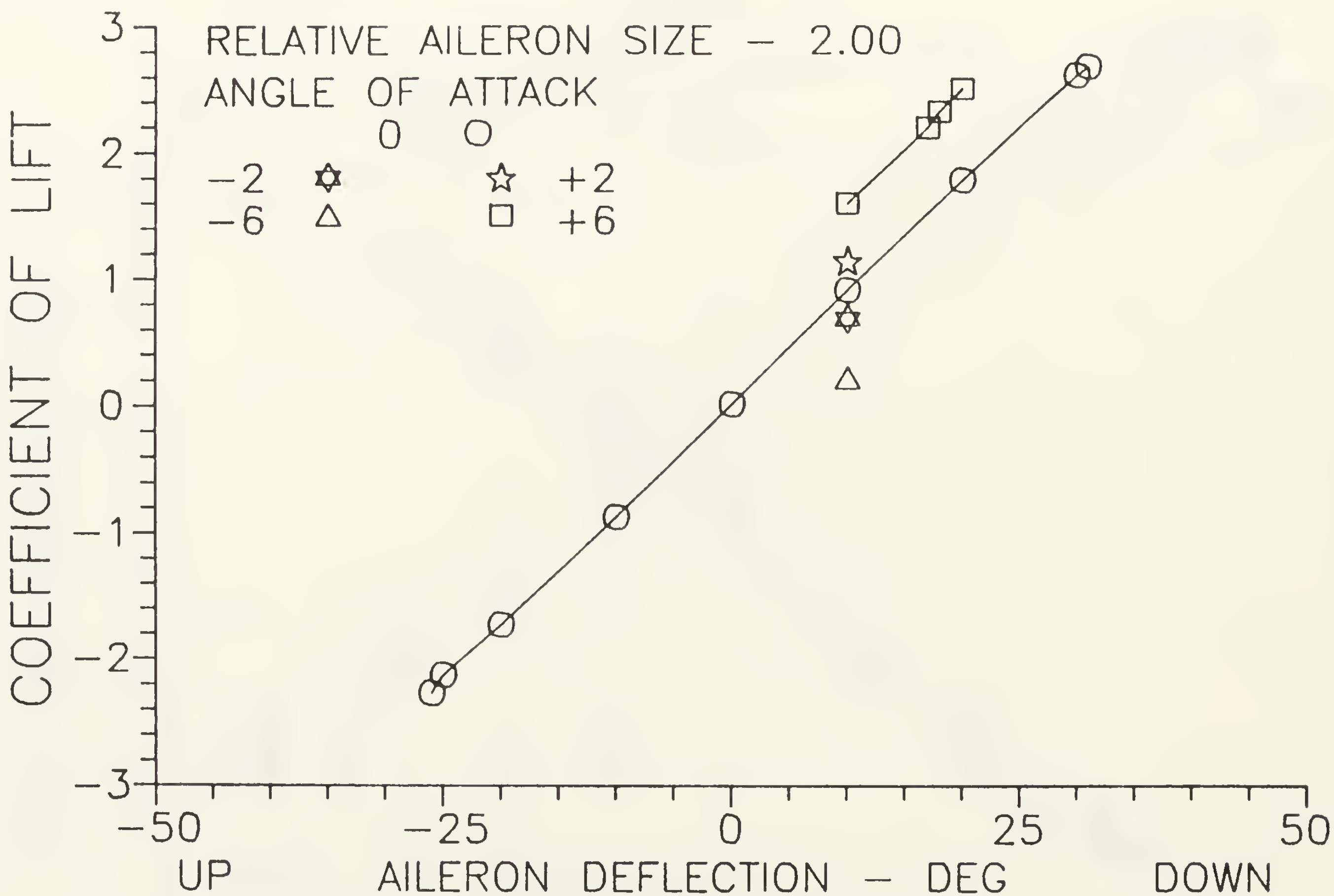

Figure 5
Effect of Aileron Deflection Angle

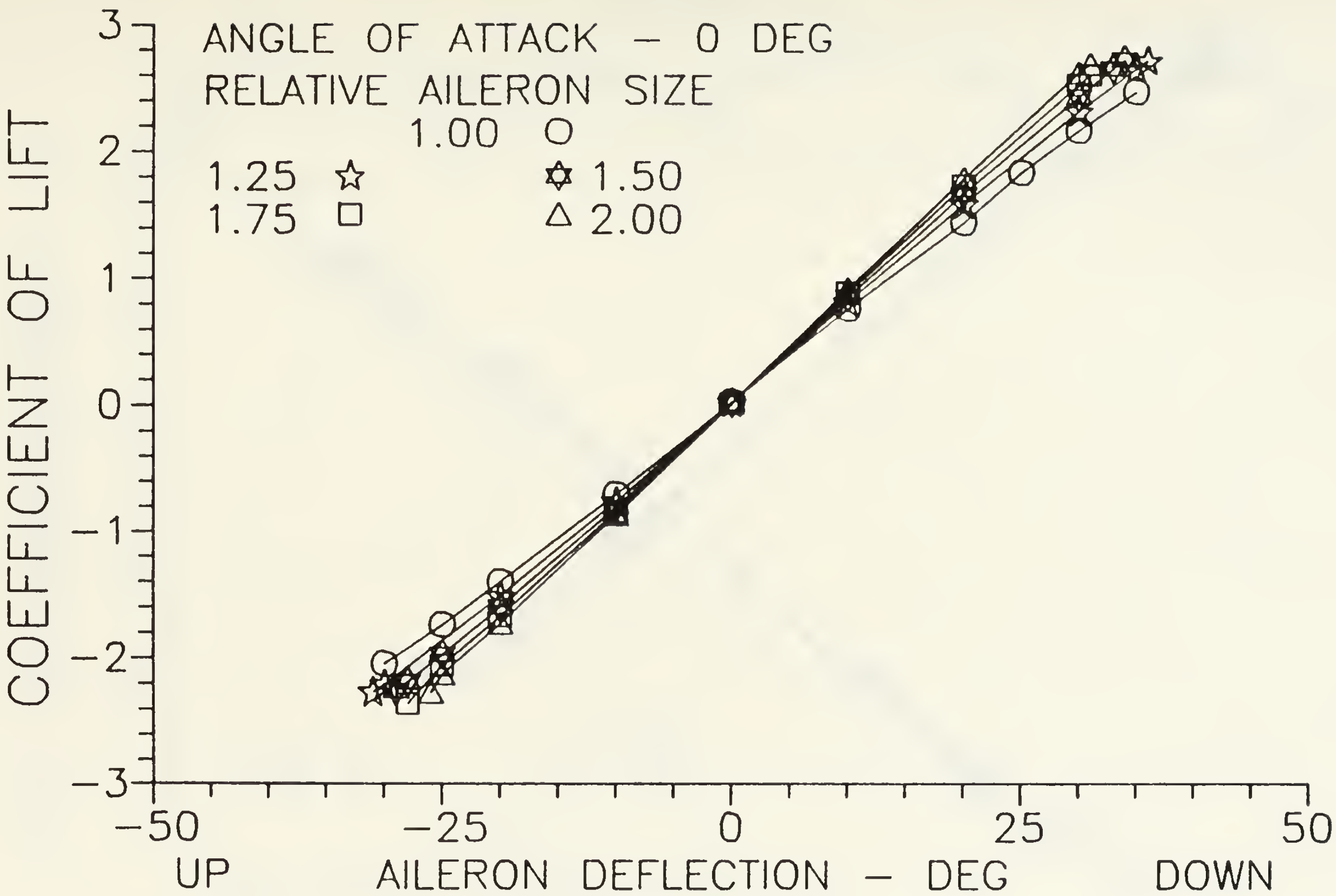

Figure 6
Effect of Aileron Deflection Angle

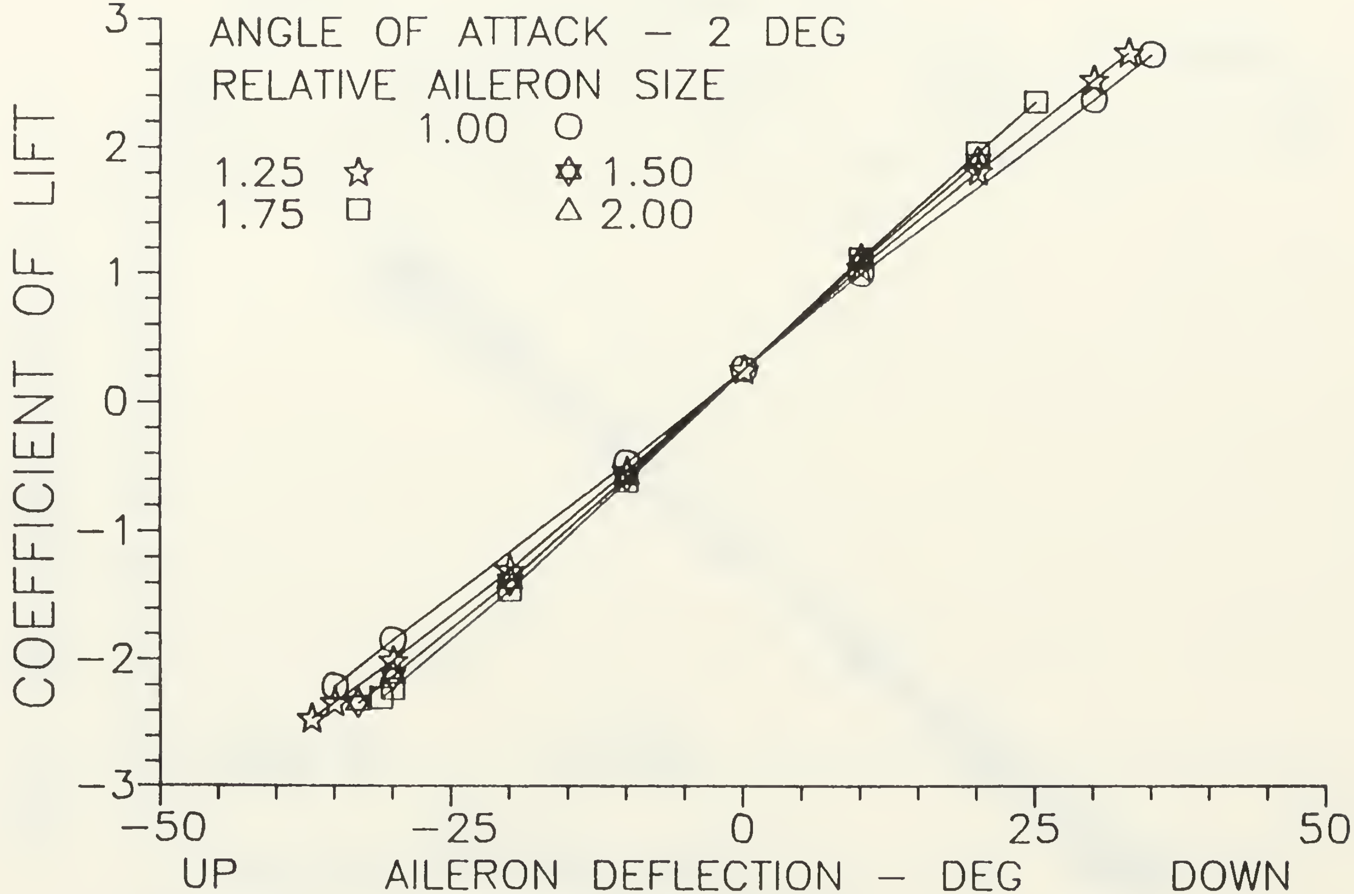

Figure 7
Effect of Aileron Deflection Angle

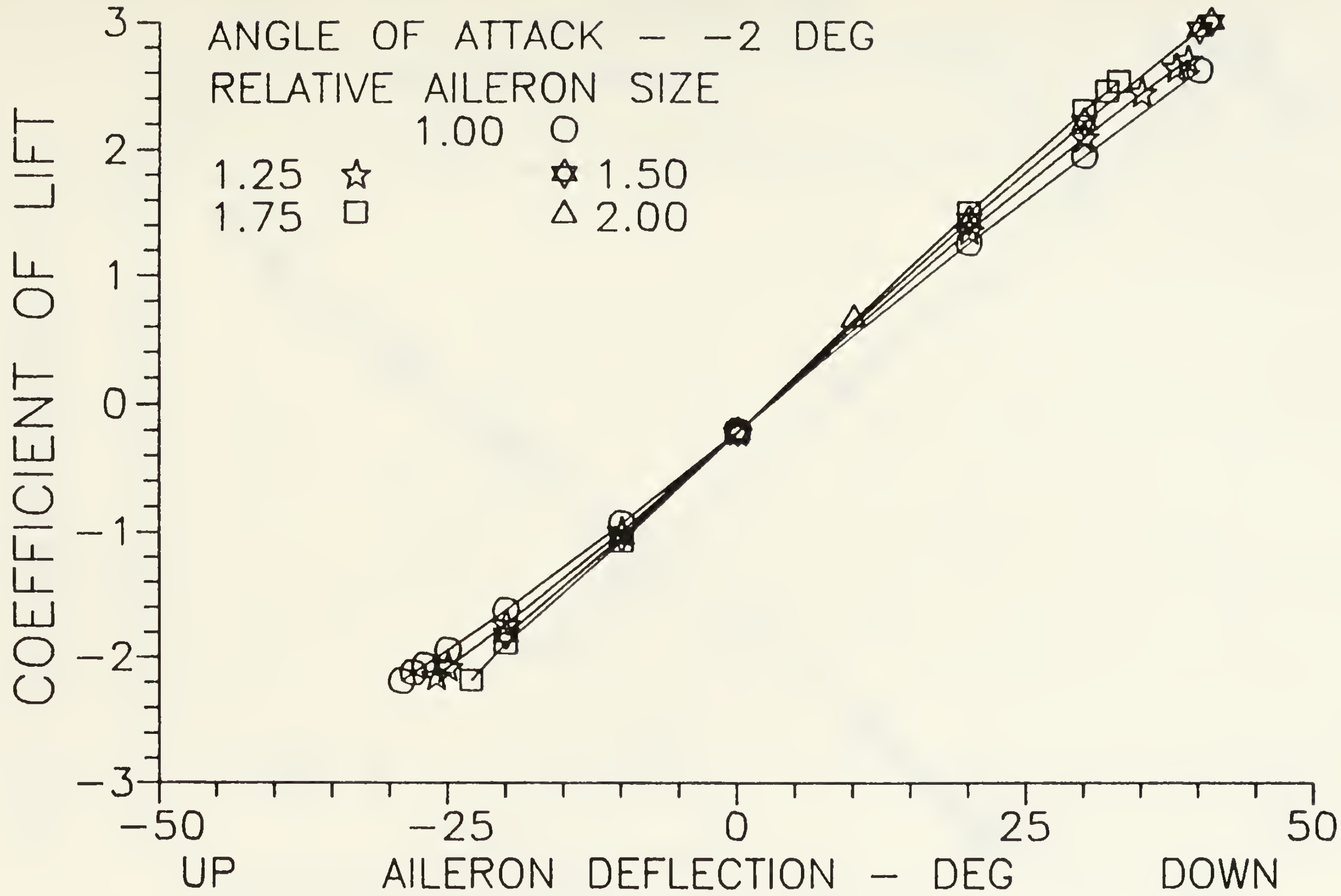

Figure 8
Effect of Aileron Deflection Angle

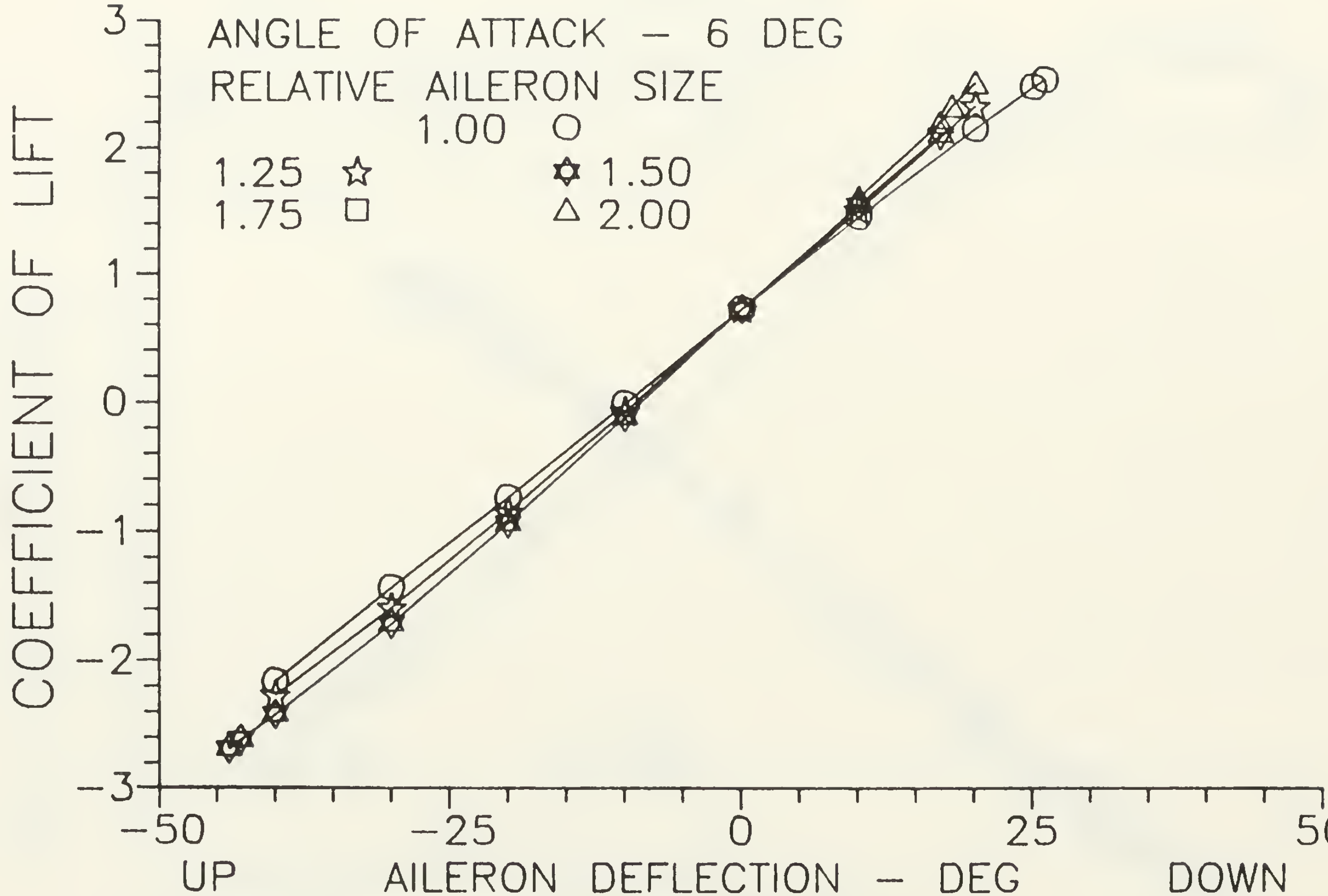

Figure 9
Effect of Aileron Deflection Angle

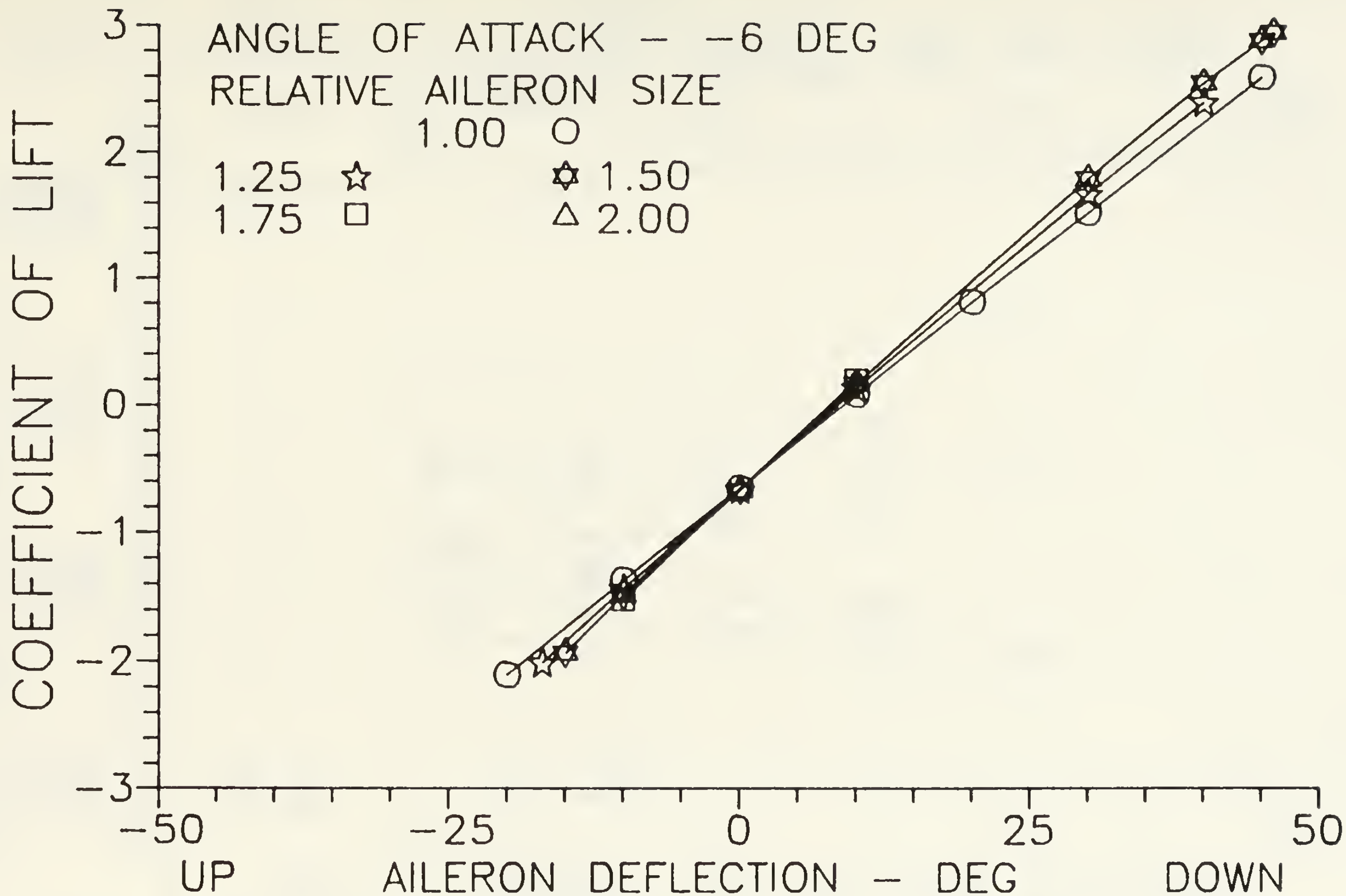

Figure 10
Effect of Aileron Deflection Angle

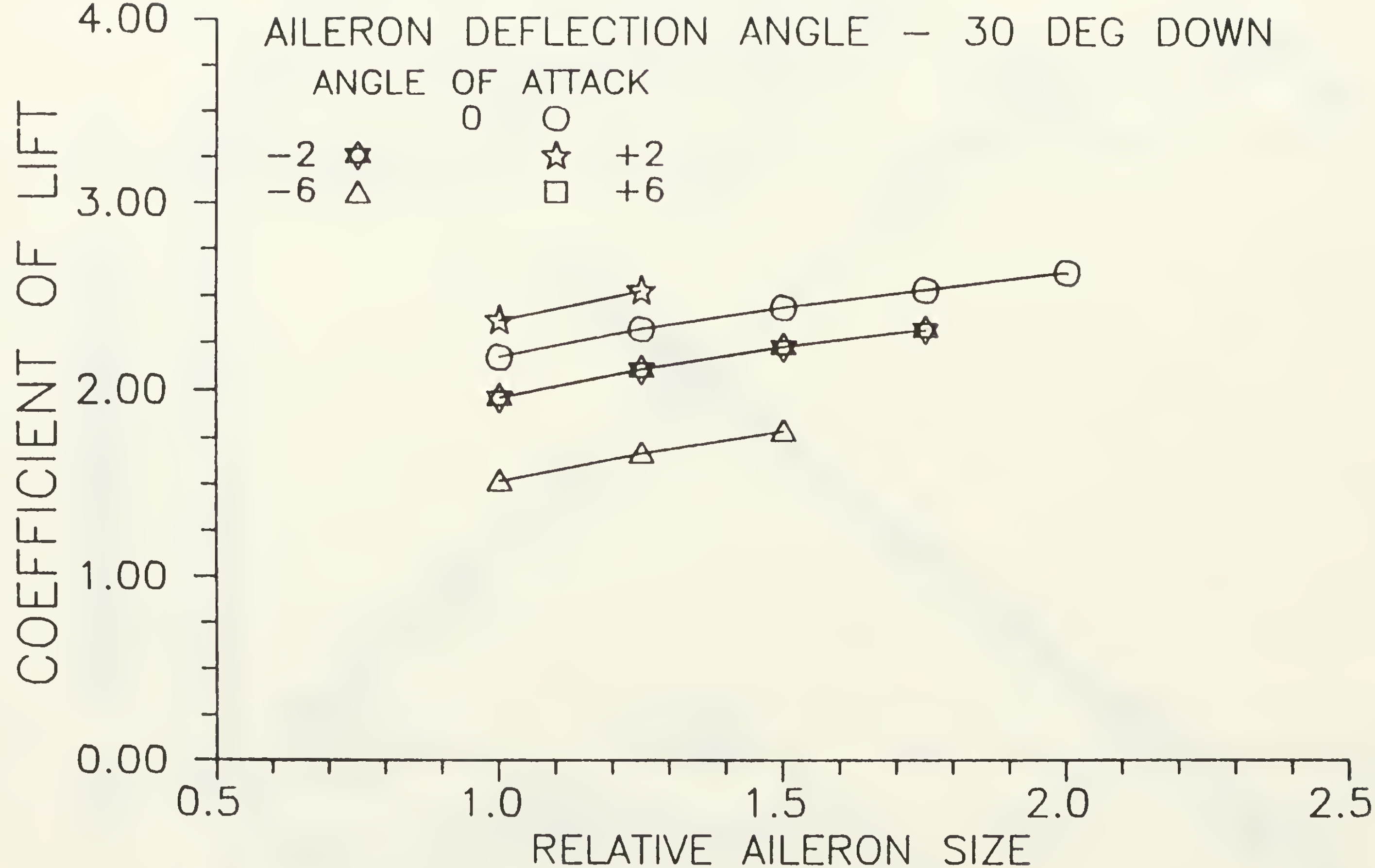

Figure 11
Effect of Relative Aileron Size

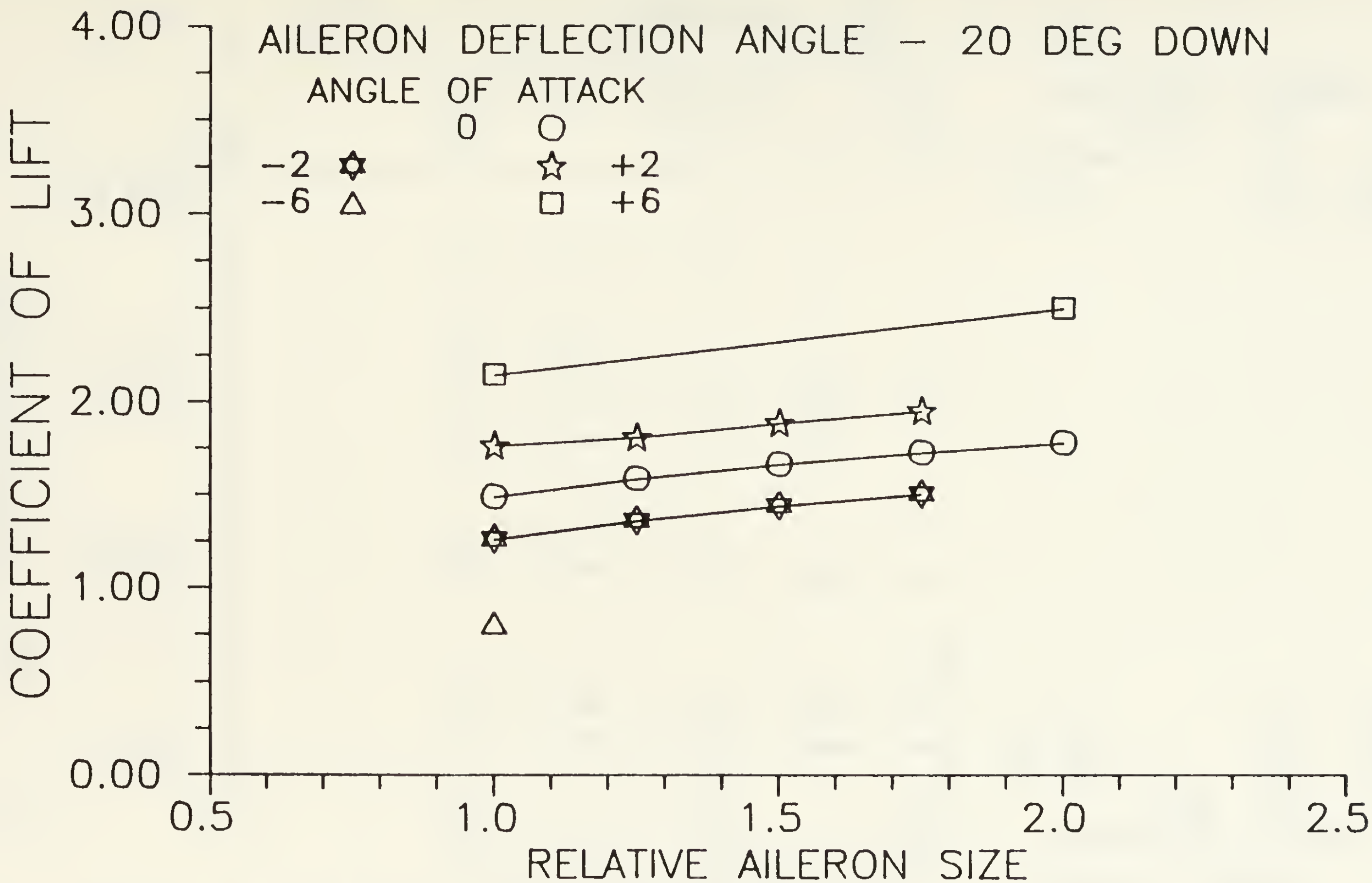

Figure 12
Effect of Relative Aileron Size

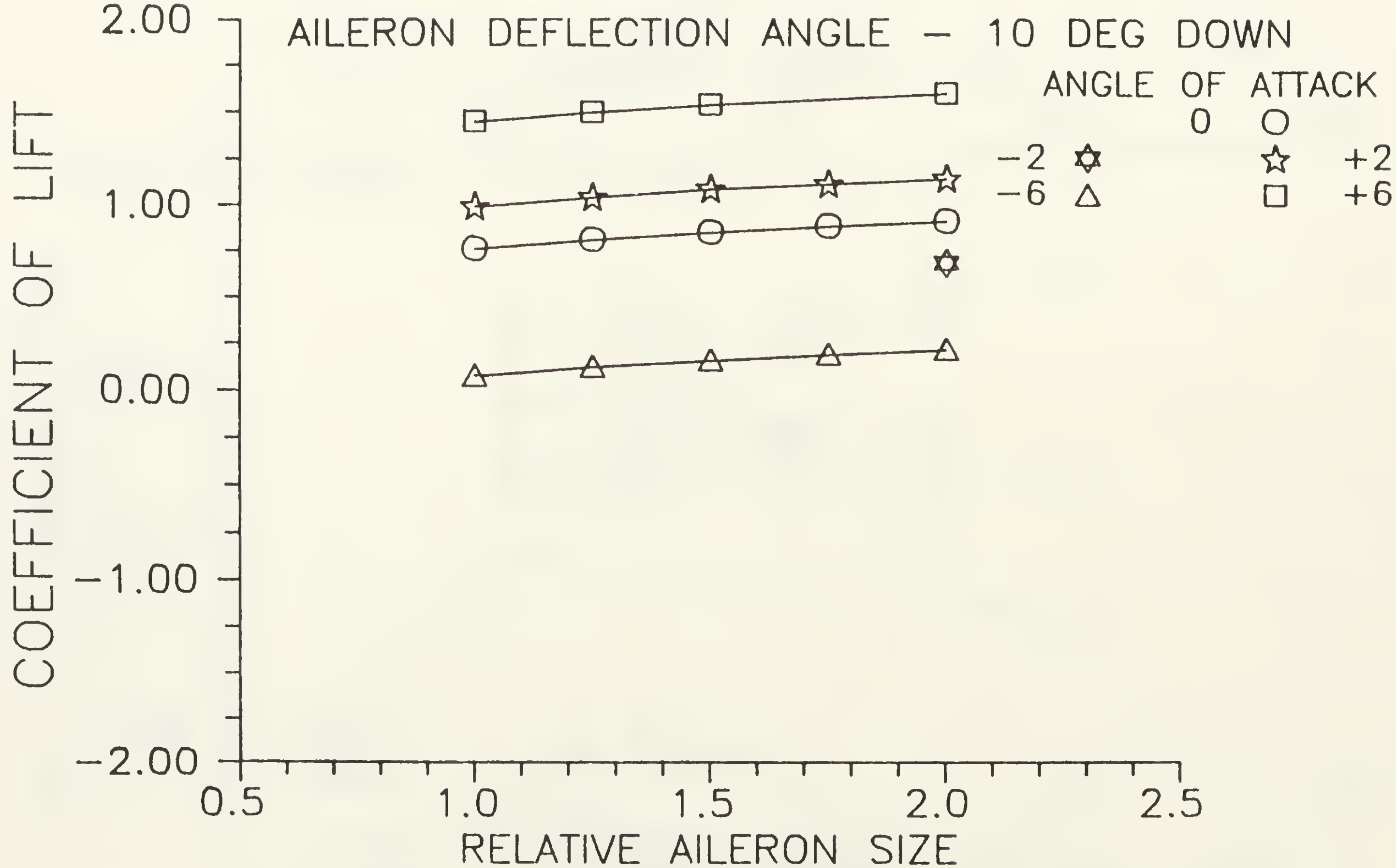

Figure 13
Effect of Relative Aileron Size

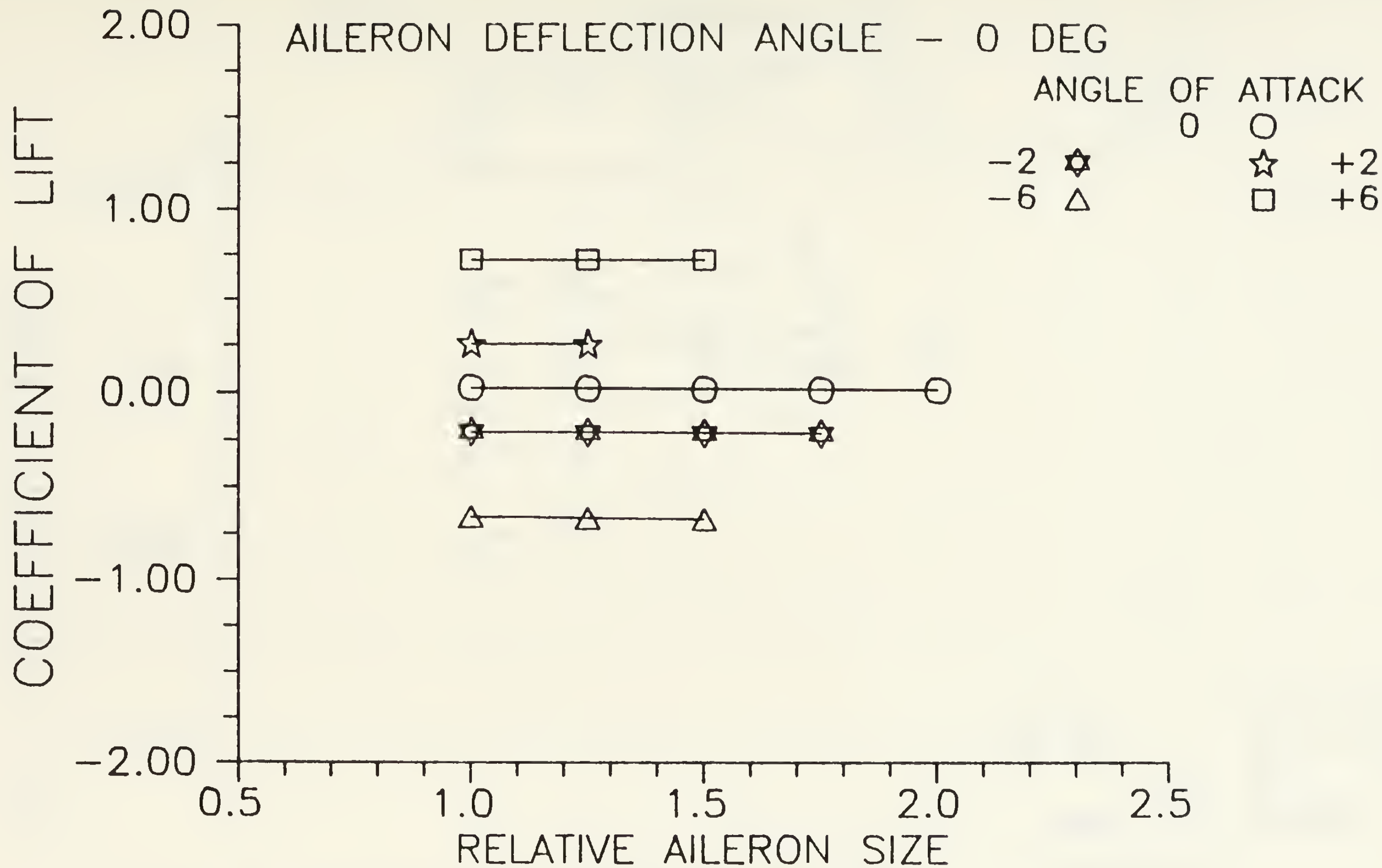

Figure 14
Effect of Relative Aileron Size

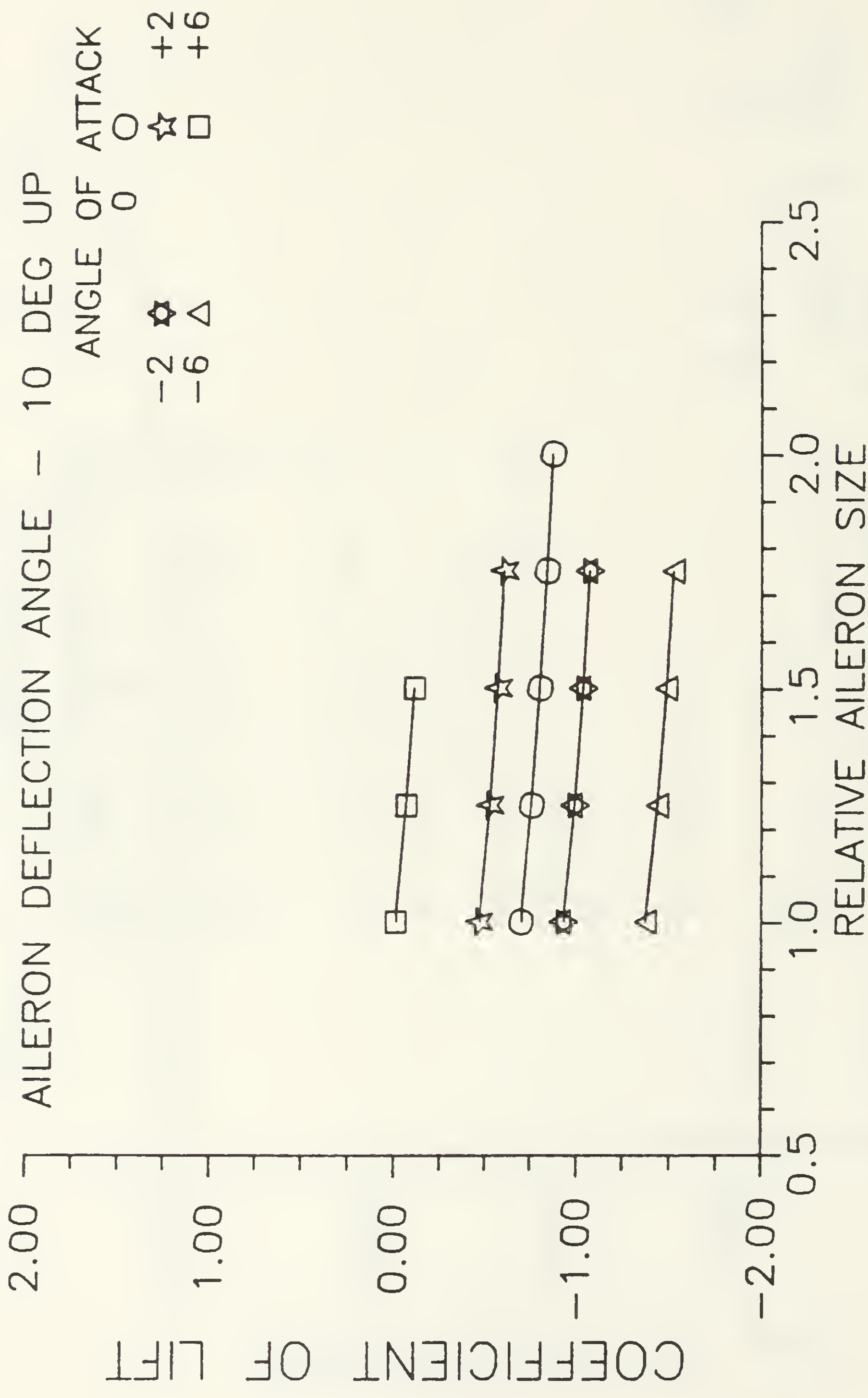

Figure 15
Effect of Relative Aileron Size

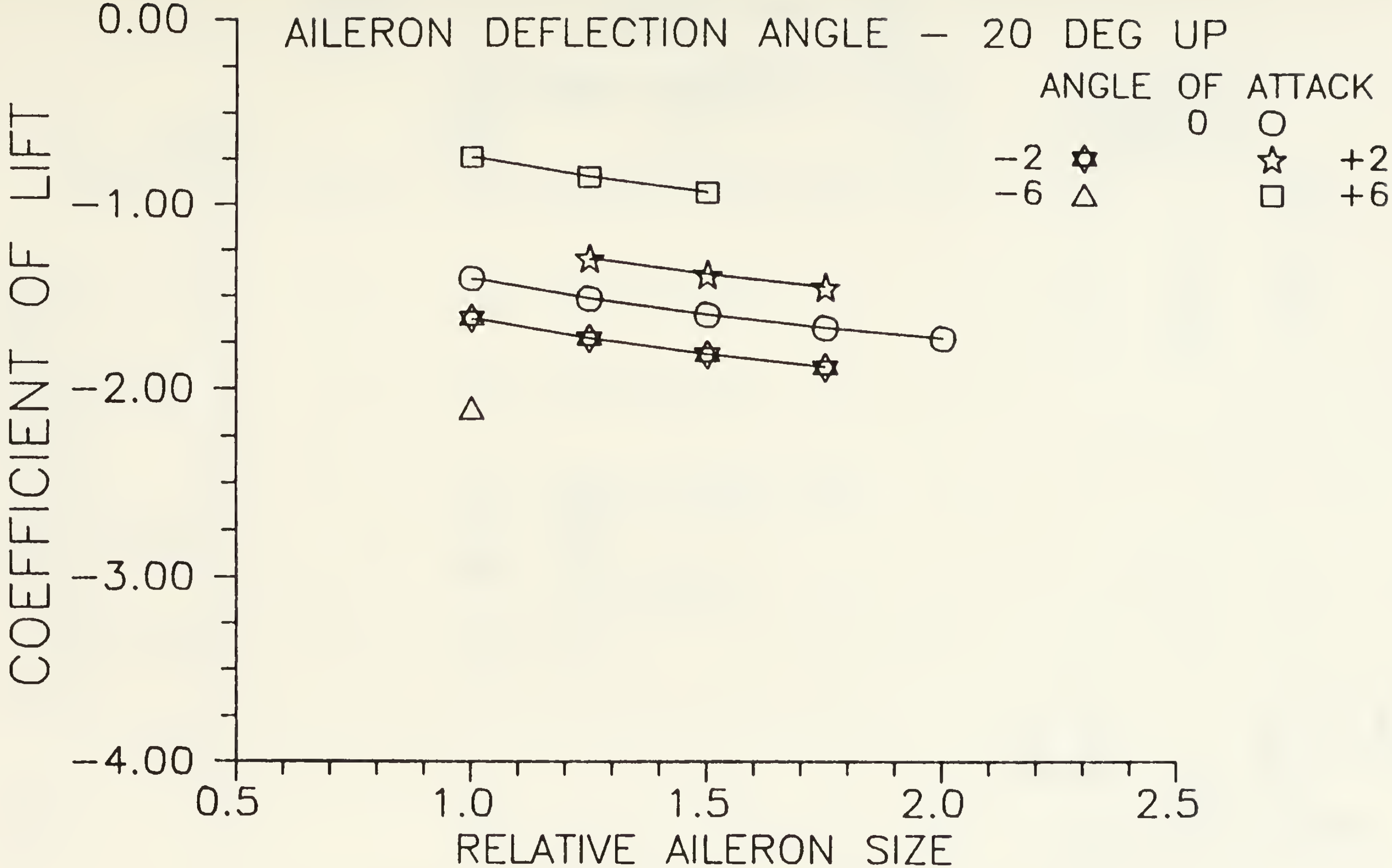

Figure 16
Effect of Relative Aileron Size

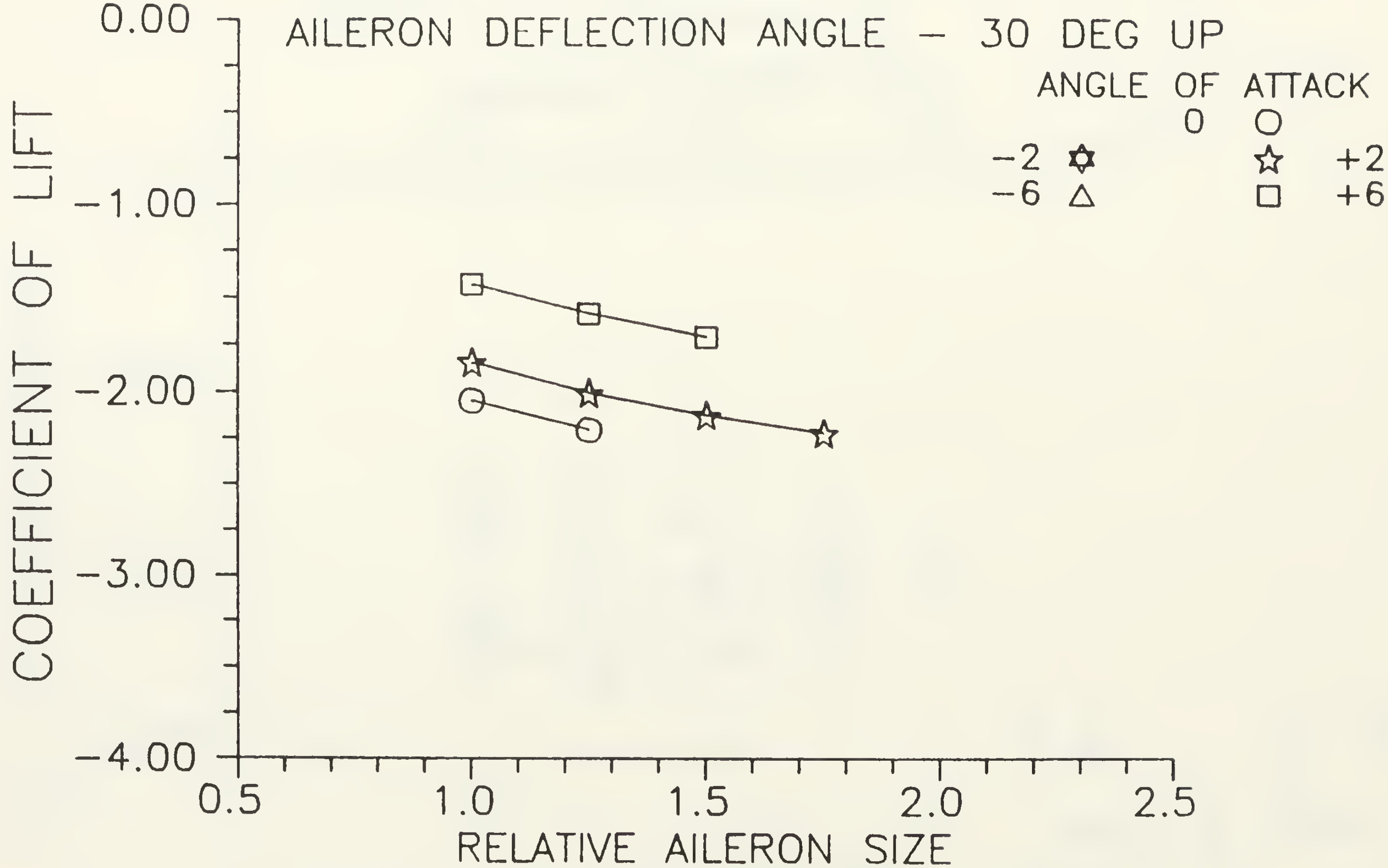

Figure 17
Effect of Relative Aileron Size

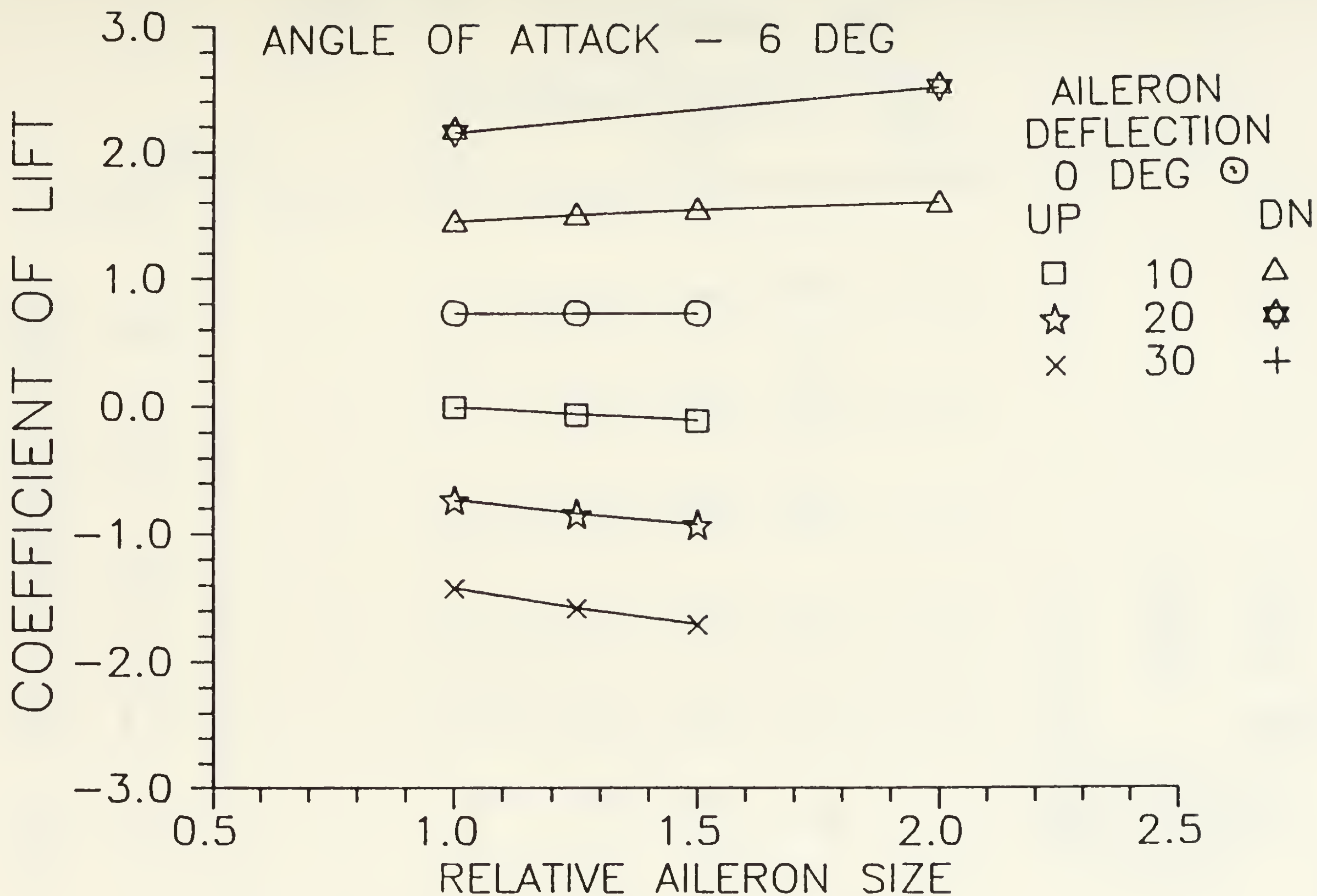

Figure 18
Effect of Relative Aileron Size

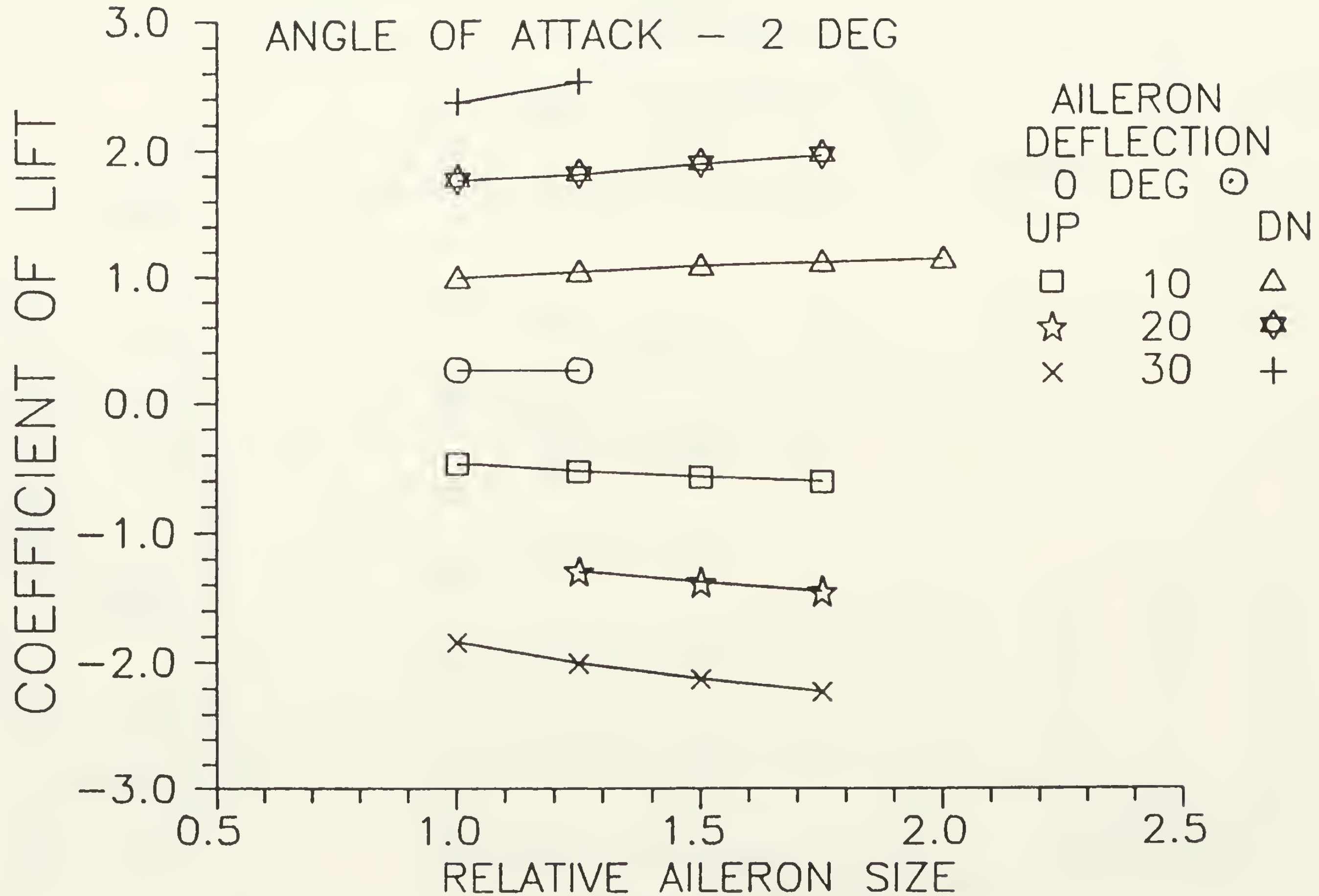

Figure 19
Effect of Relative Aileron Size

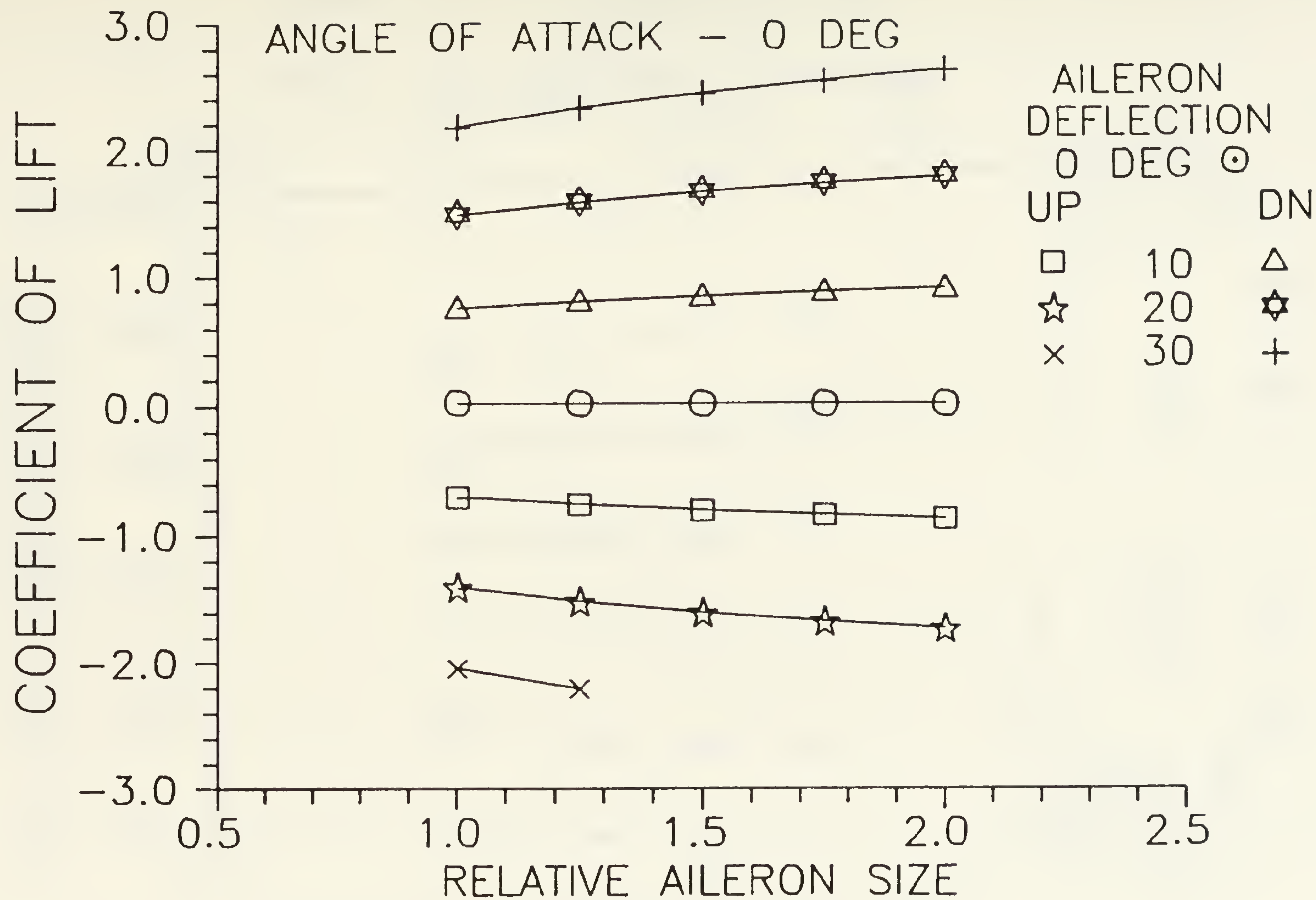

Figure 20
Effect of Relative Aileron Size

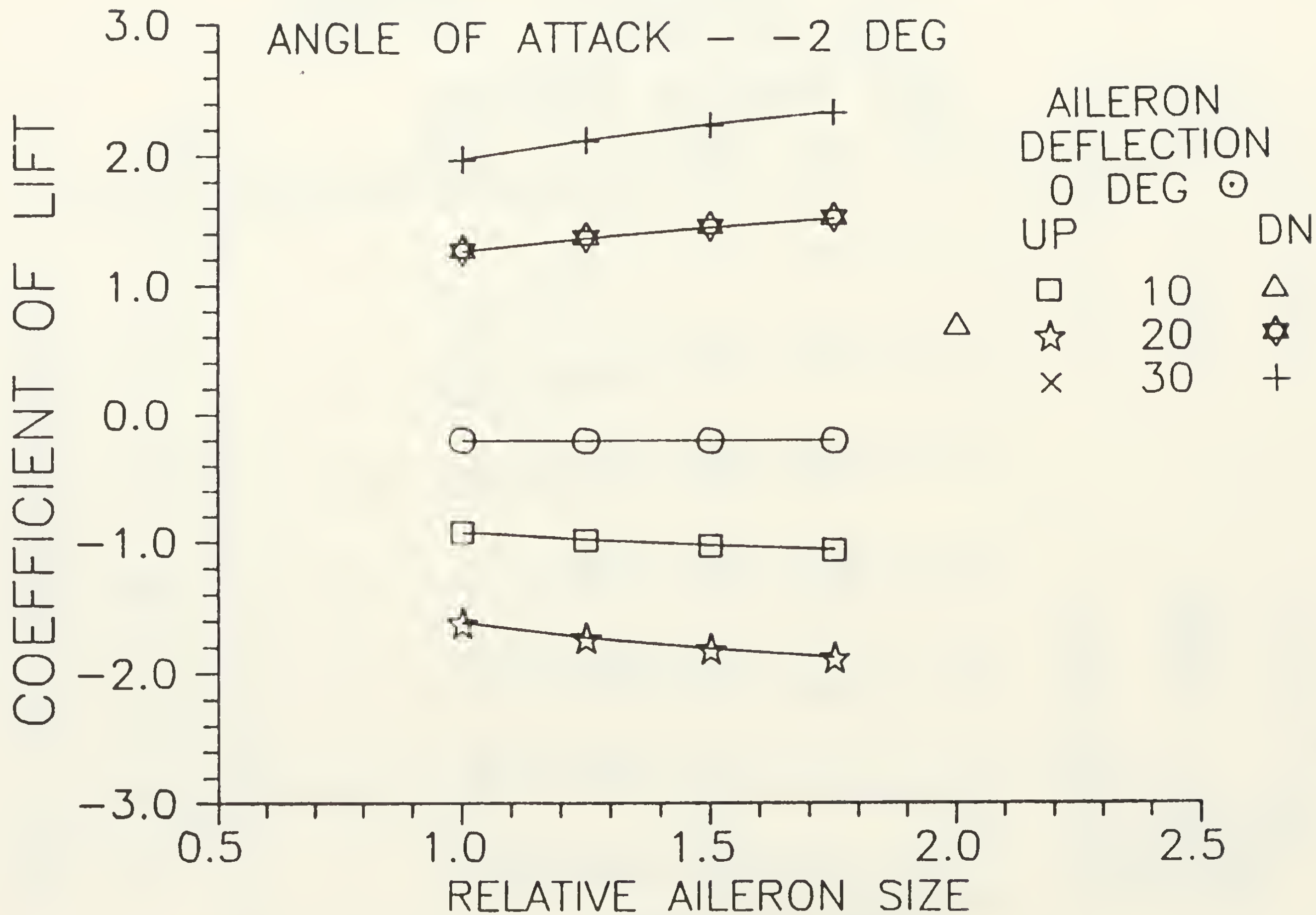

Figure 21
Effect of Relative Aileron Size

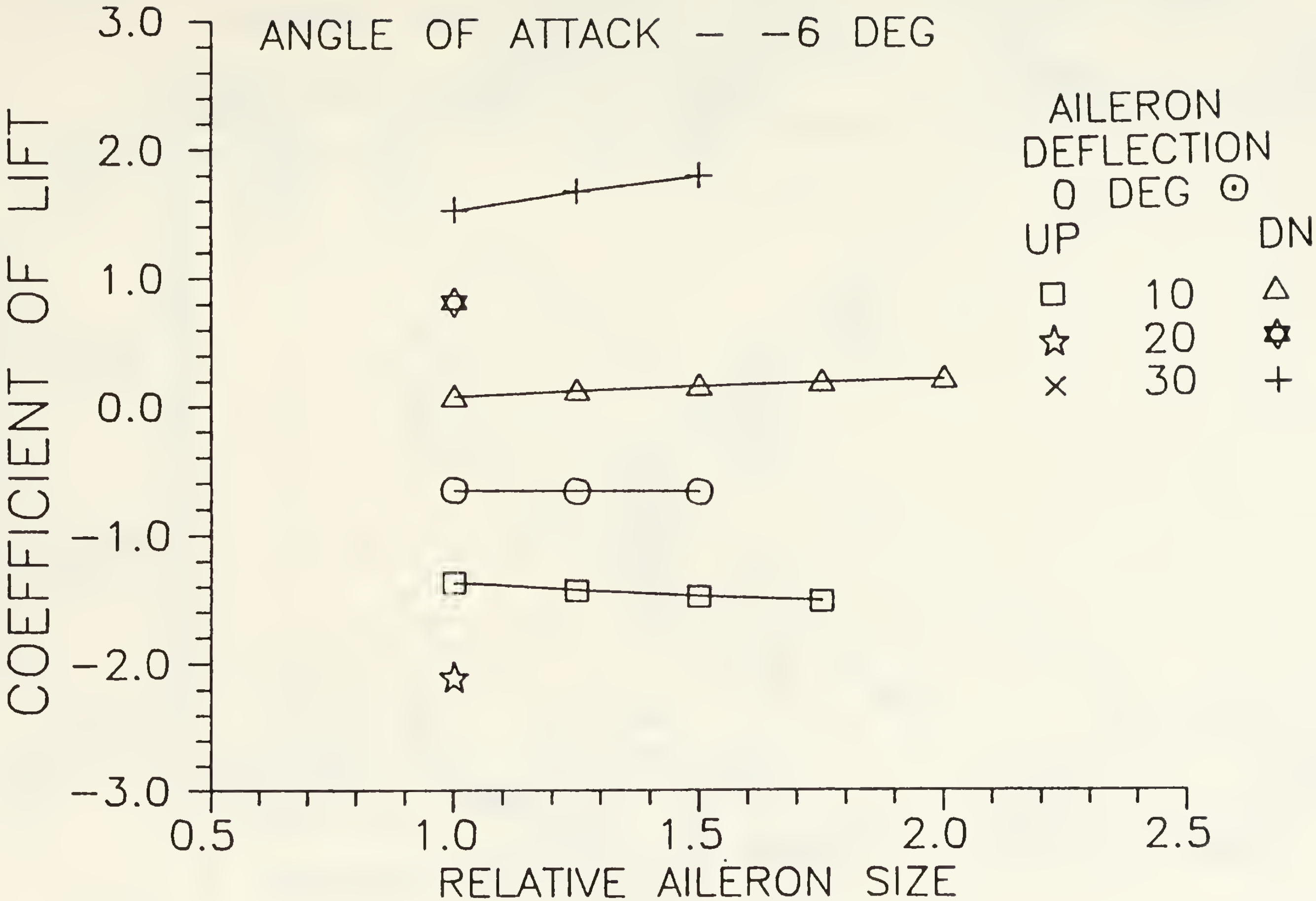

Figure 22
Effect of Relative Aileron Size

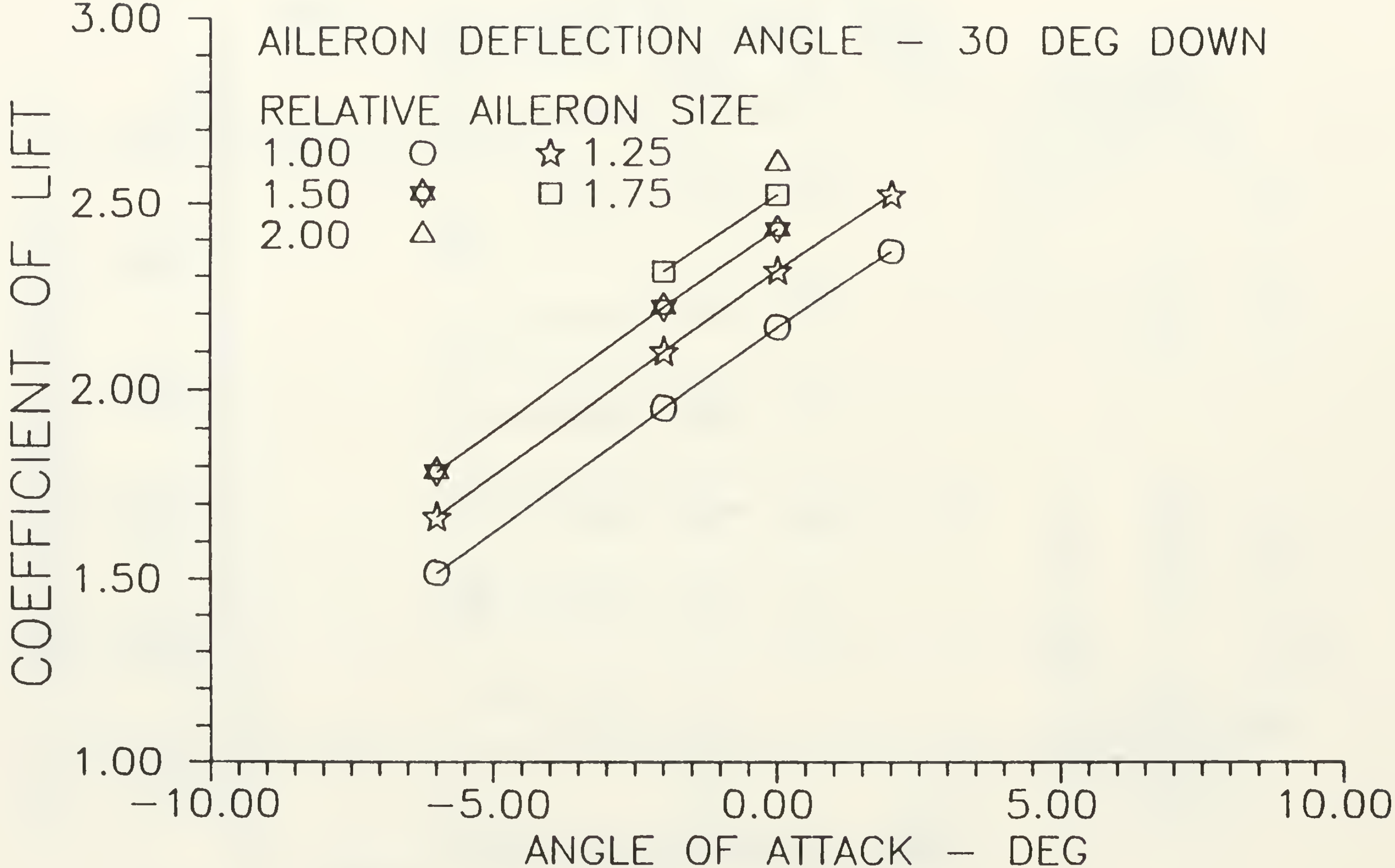

Figure 23
Effect of Angle of Attack

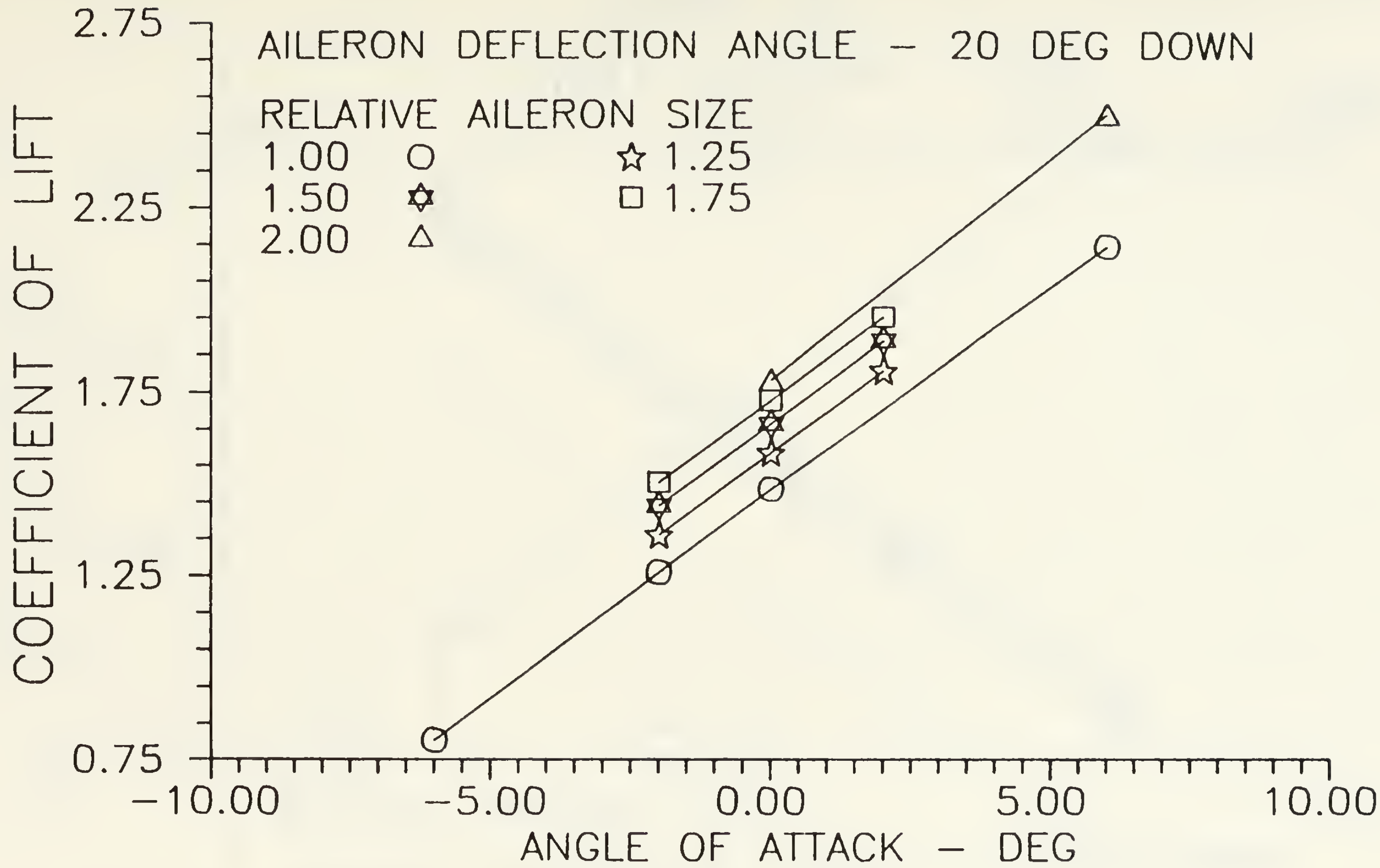

Figure 24
Effect of Angle of Attack

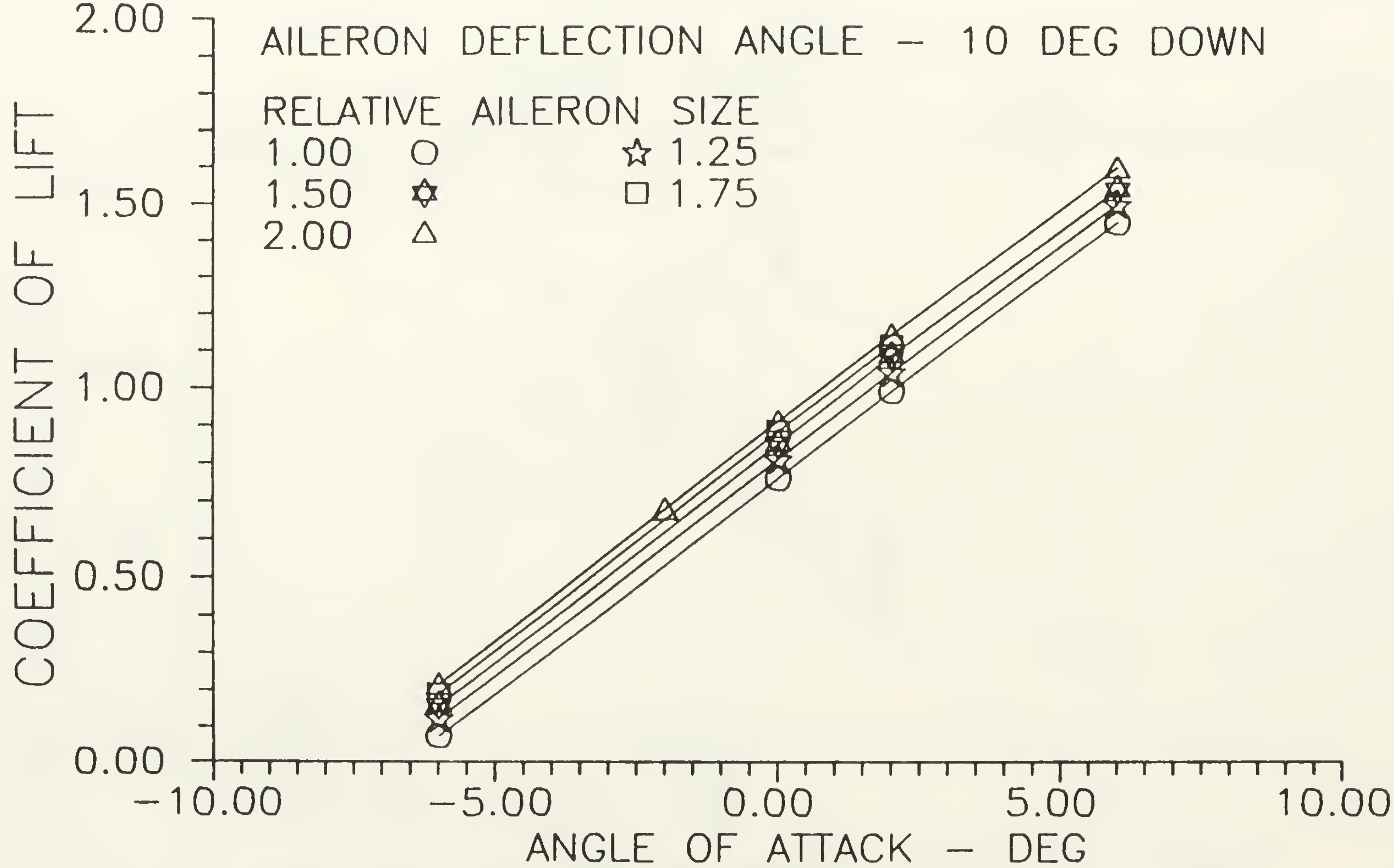

Figure 25
Effect of Angle of Attack

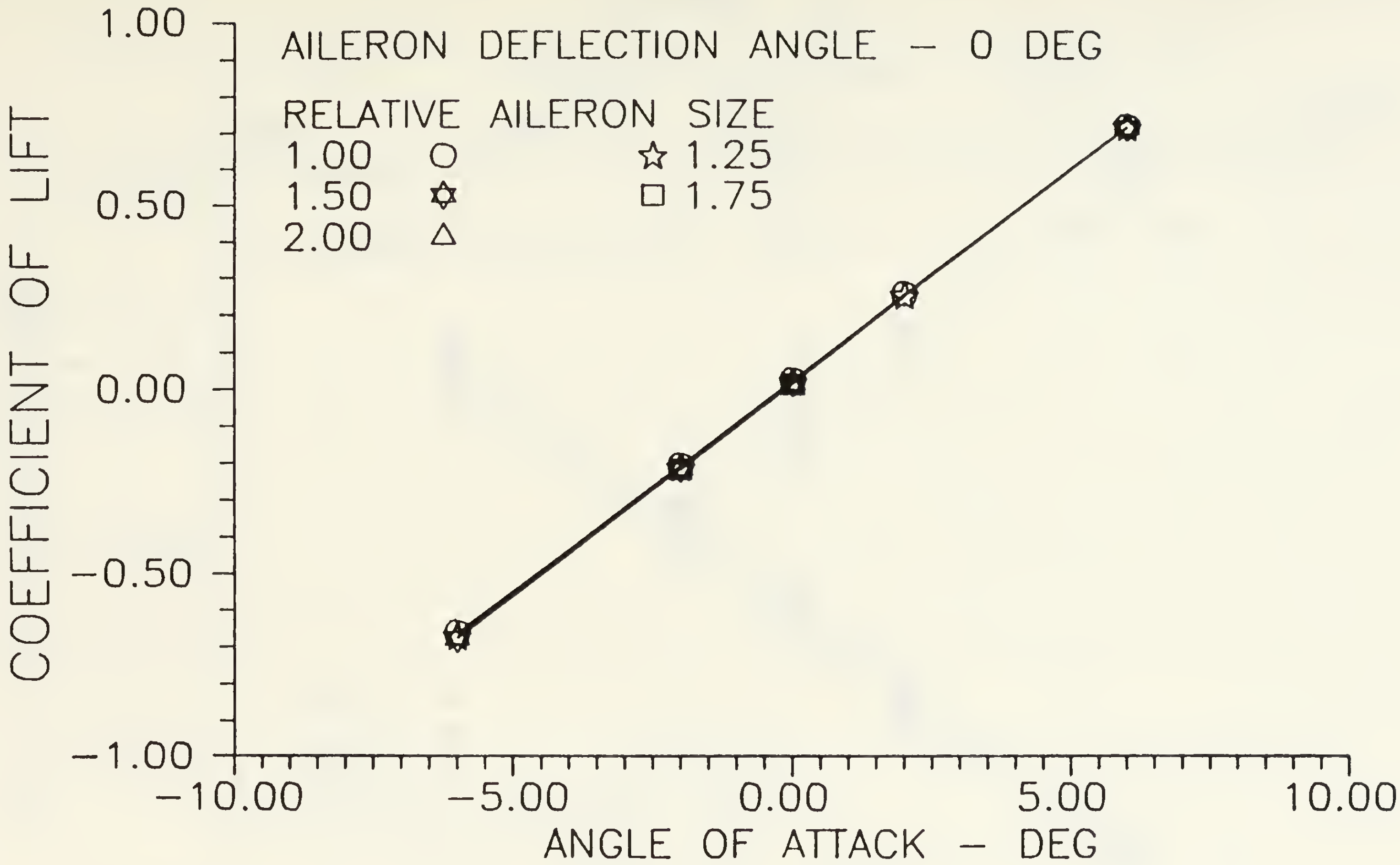

Figure 26
Effect of Angle of Attack

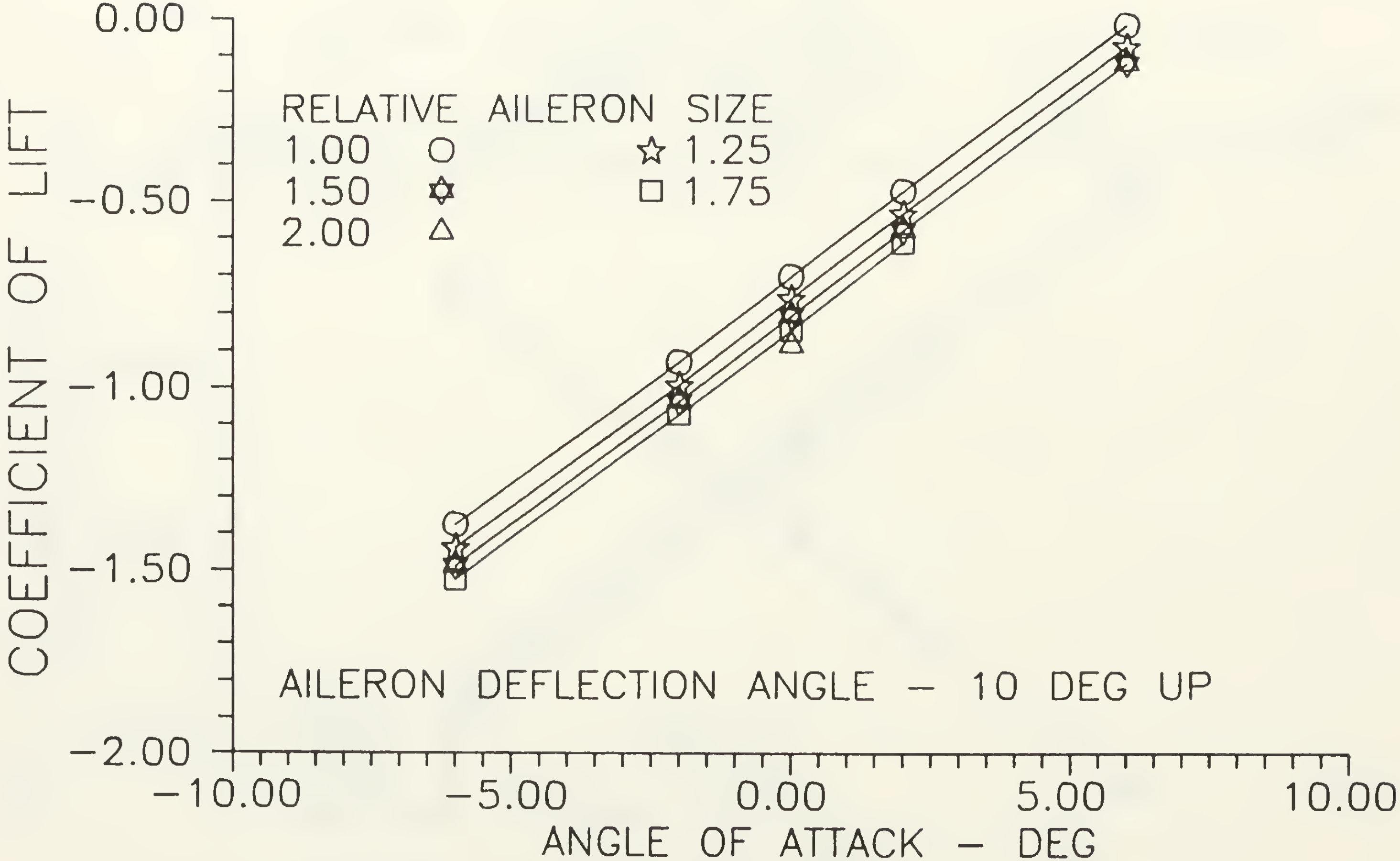

Figure 27
Effect of Angle of Attack

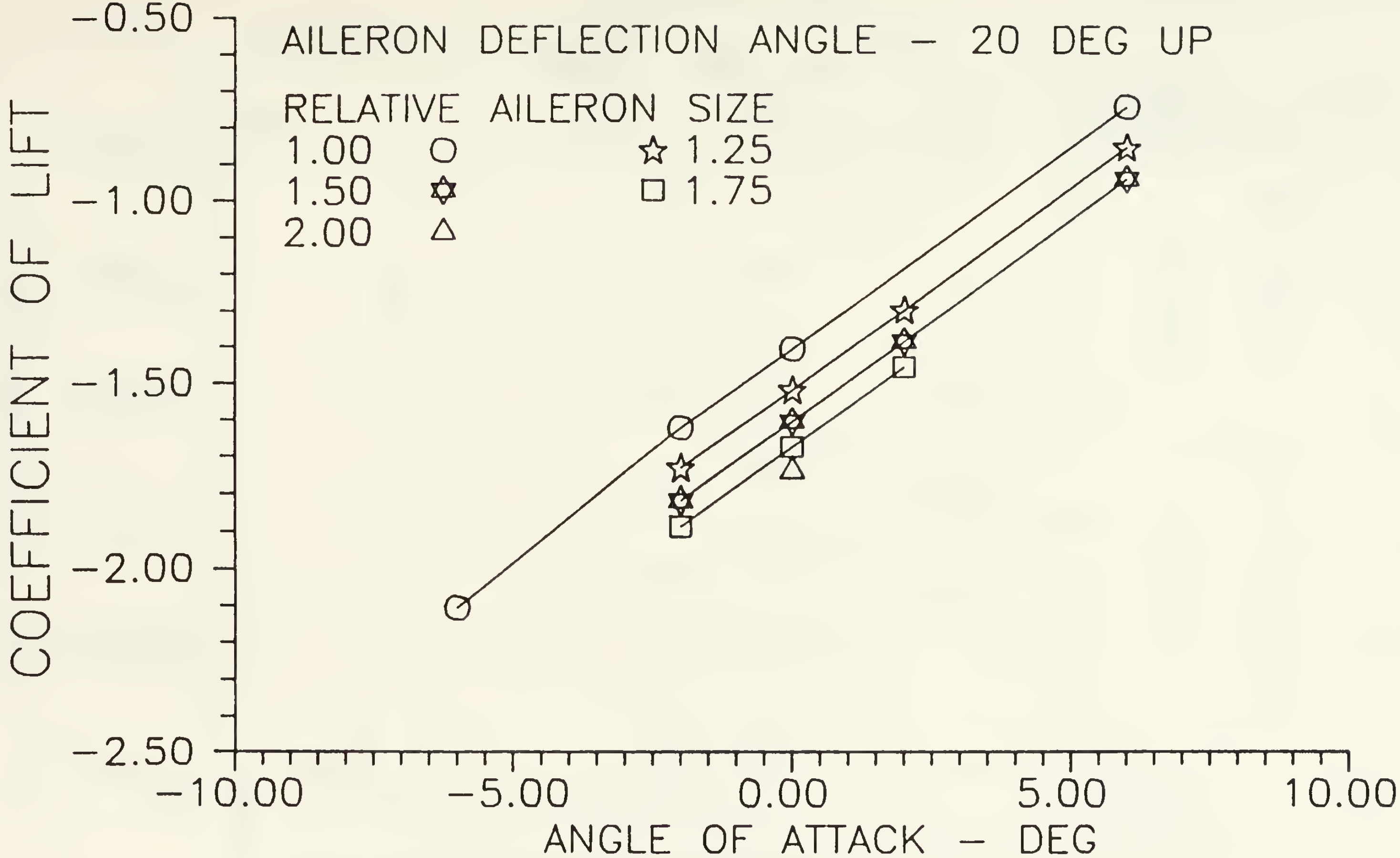

Figure 28
Effect of Angle of Attack

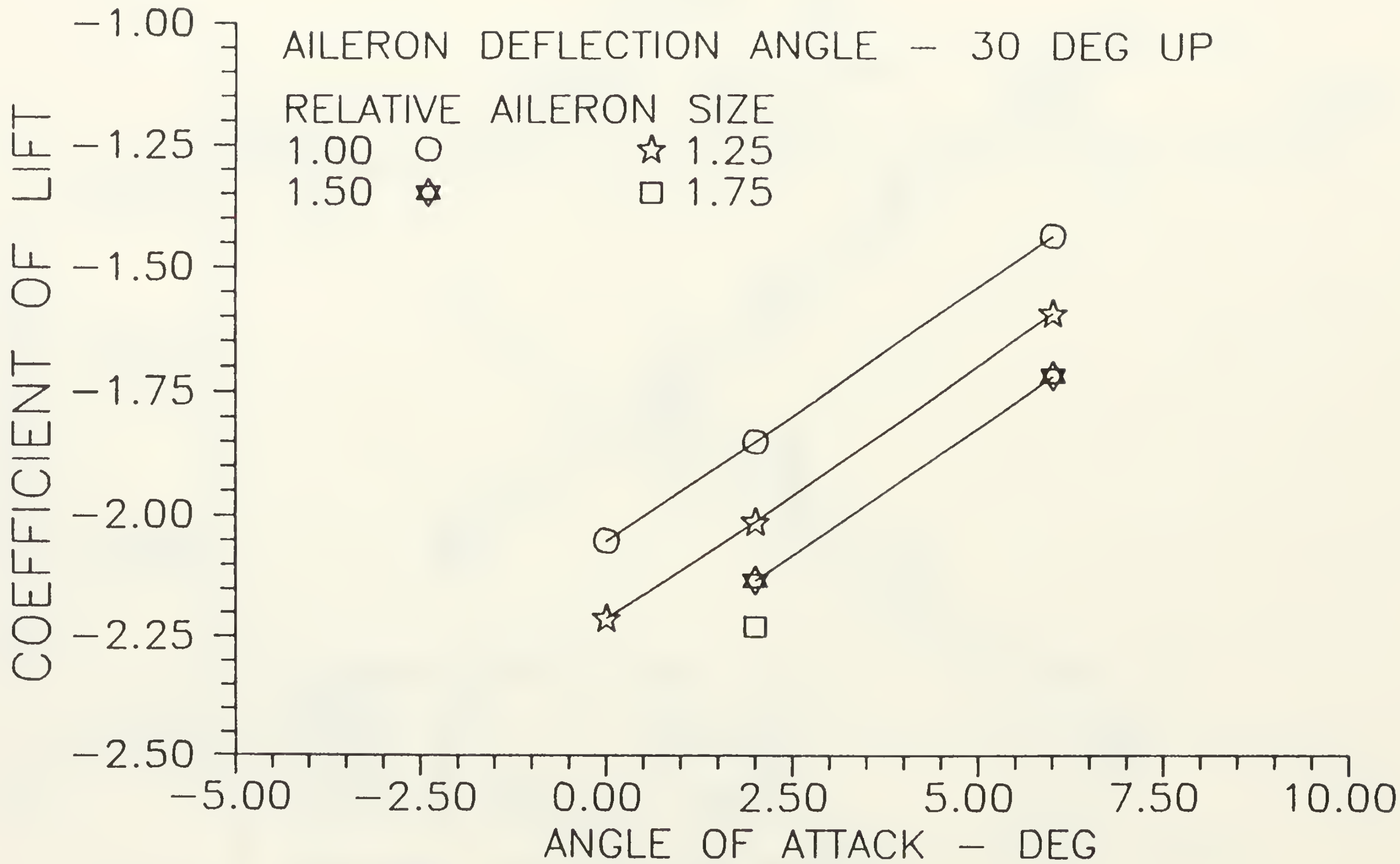

Figure 29
Effect of Angle of Attack

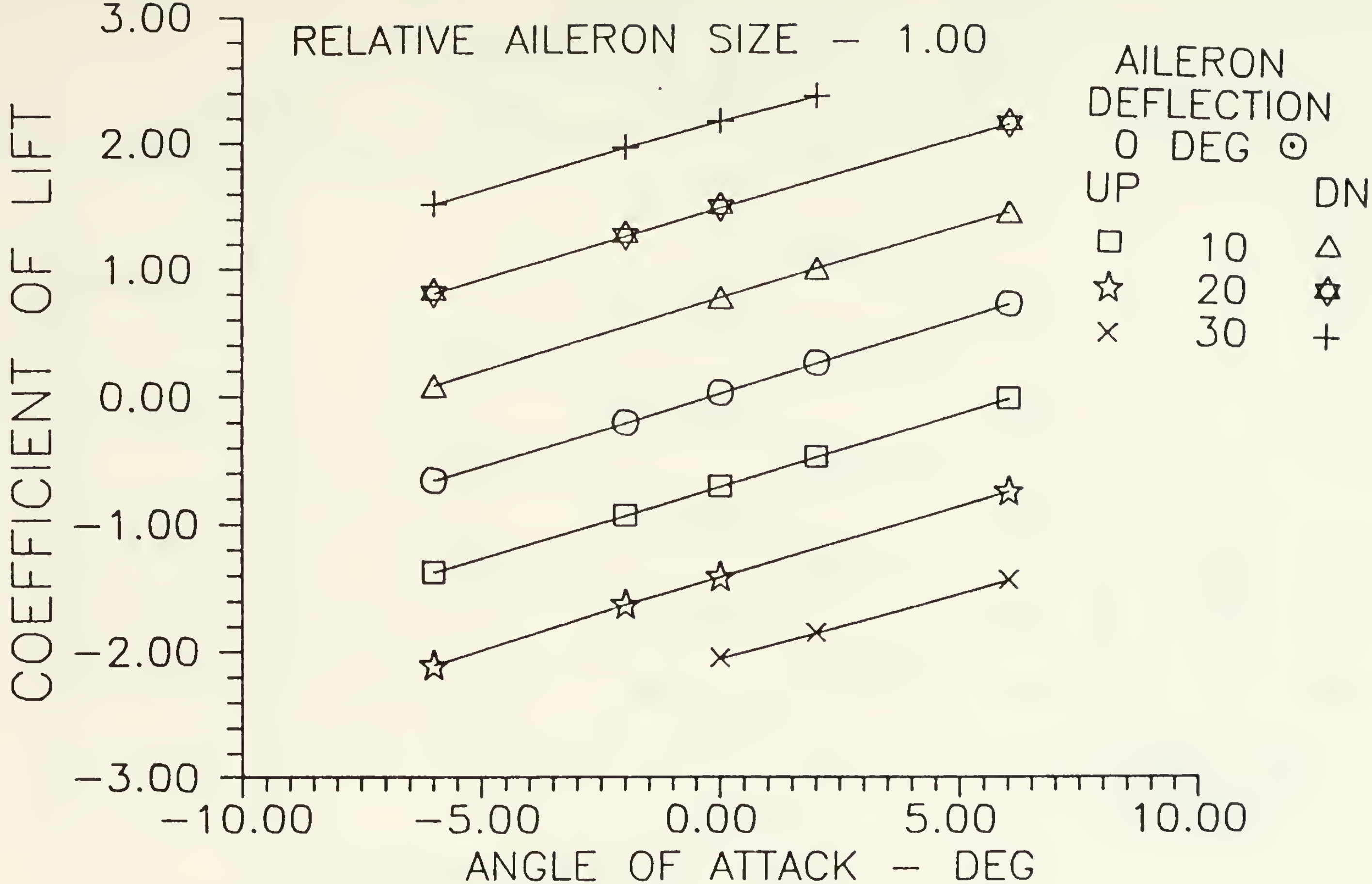

Figure 30
Effect of Angle of Attack

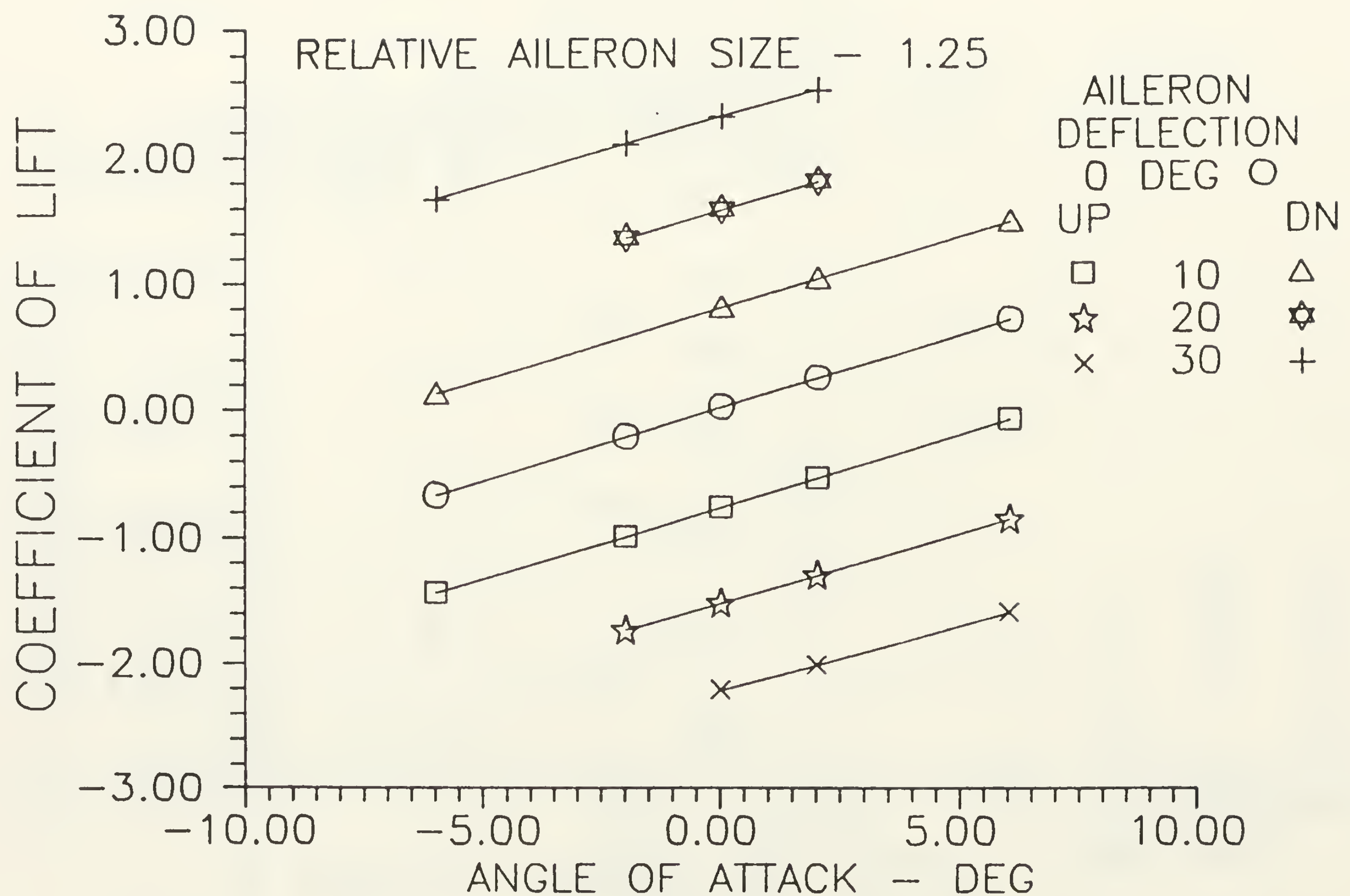

Figure 31
Effect of Angle of Attack

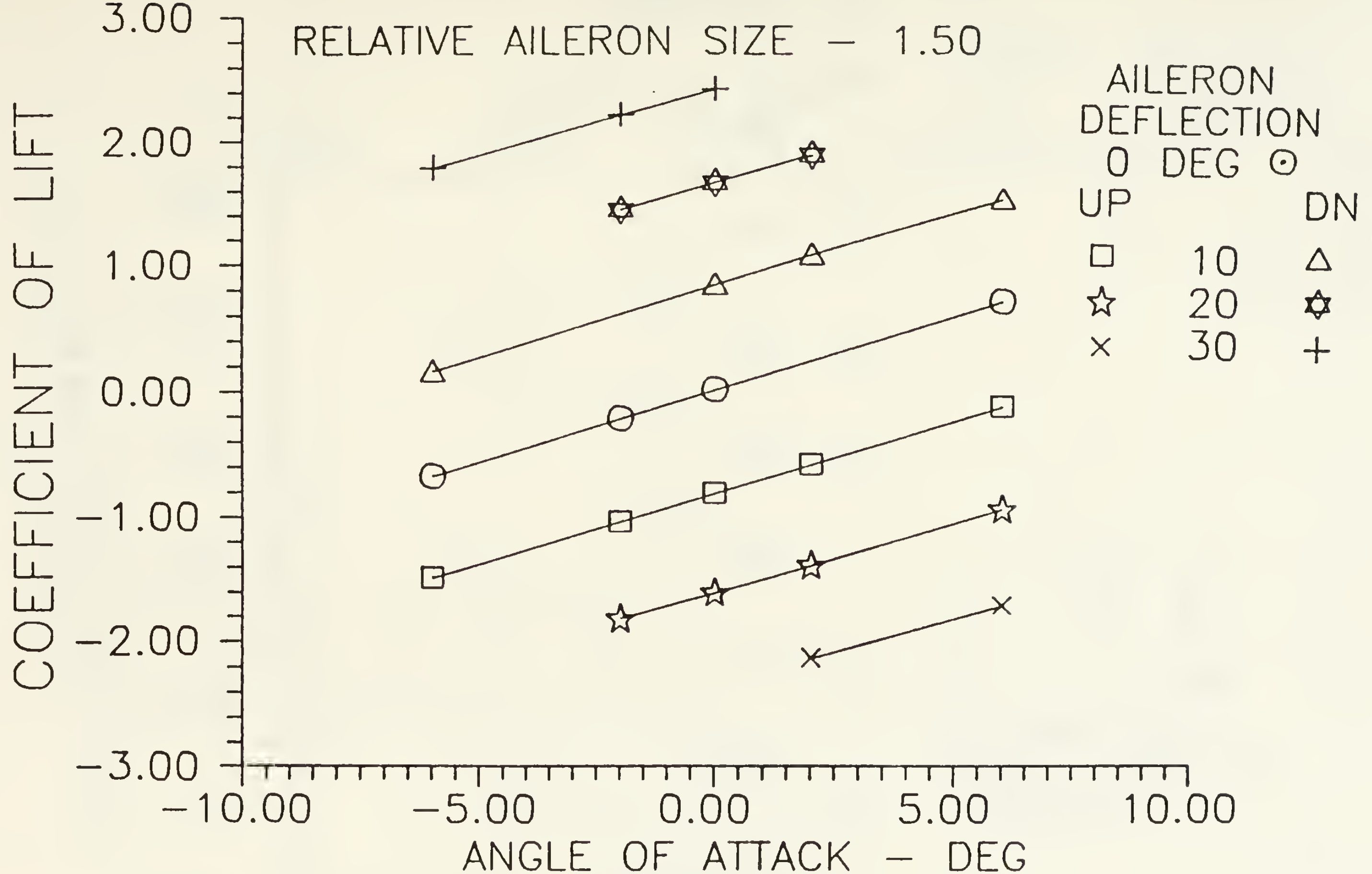

Figure 32
Effect of Angle of Attack

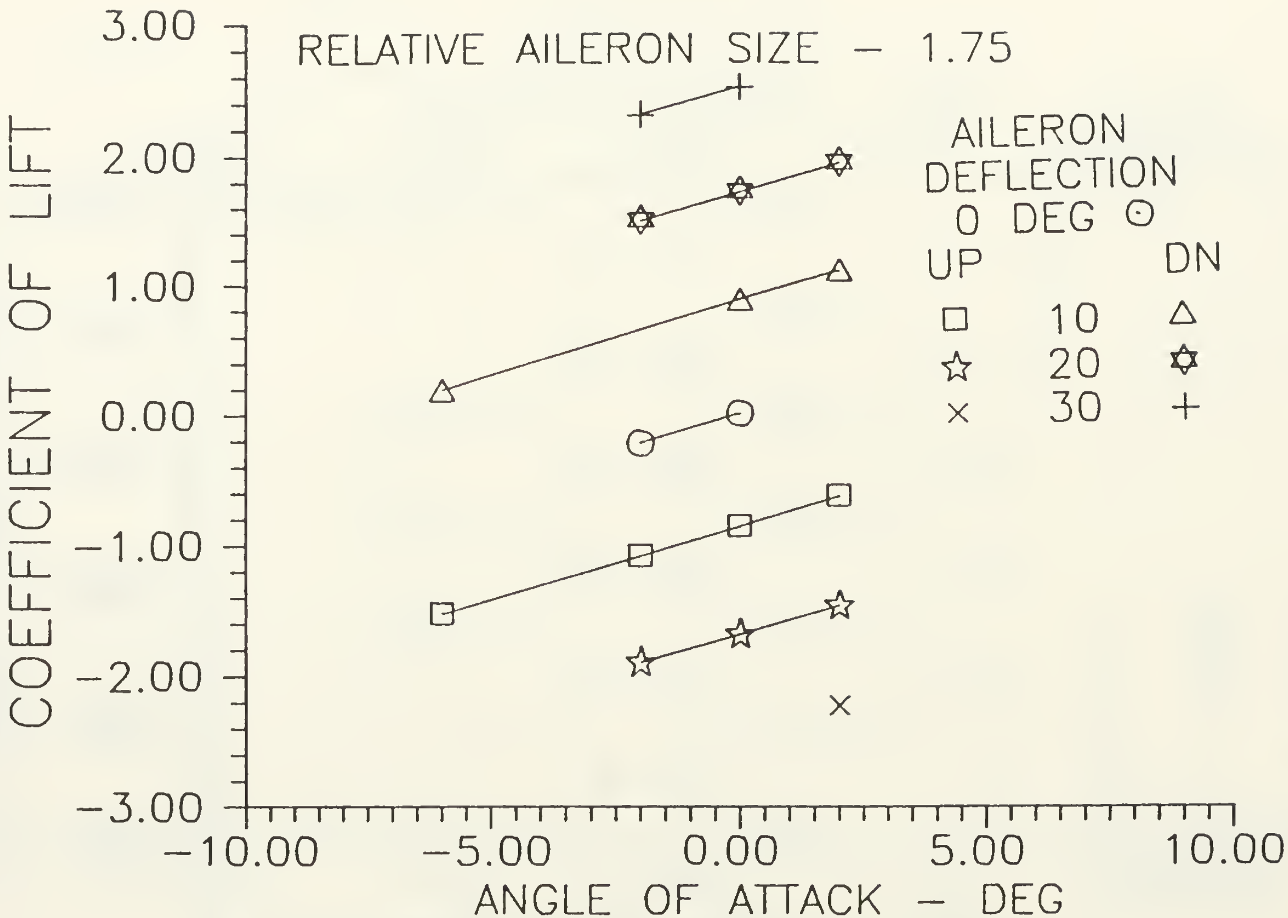

Figure 33
Effect of Angle of Attack

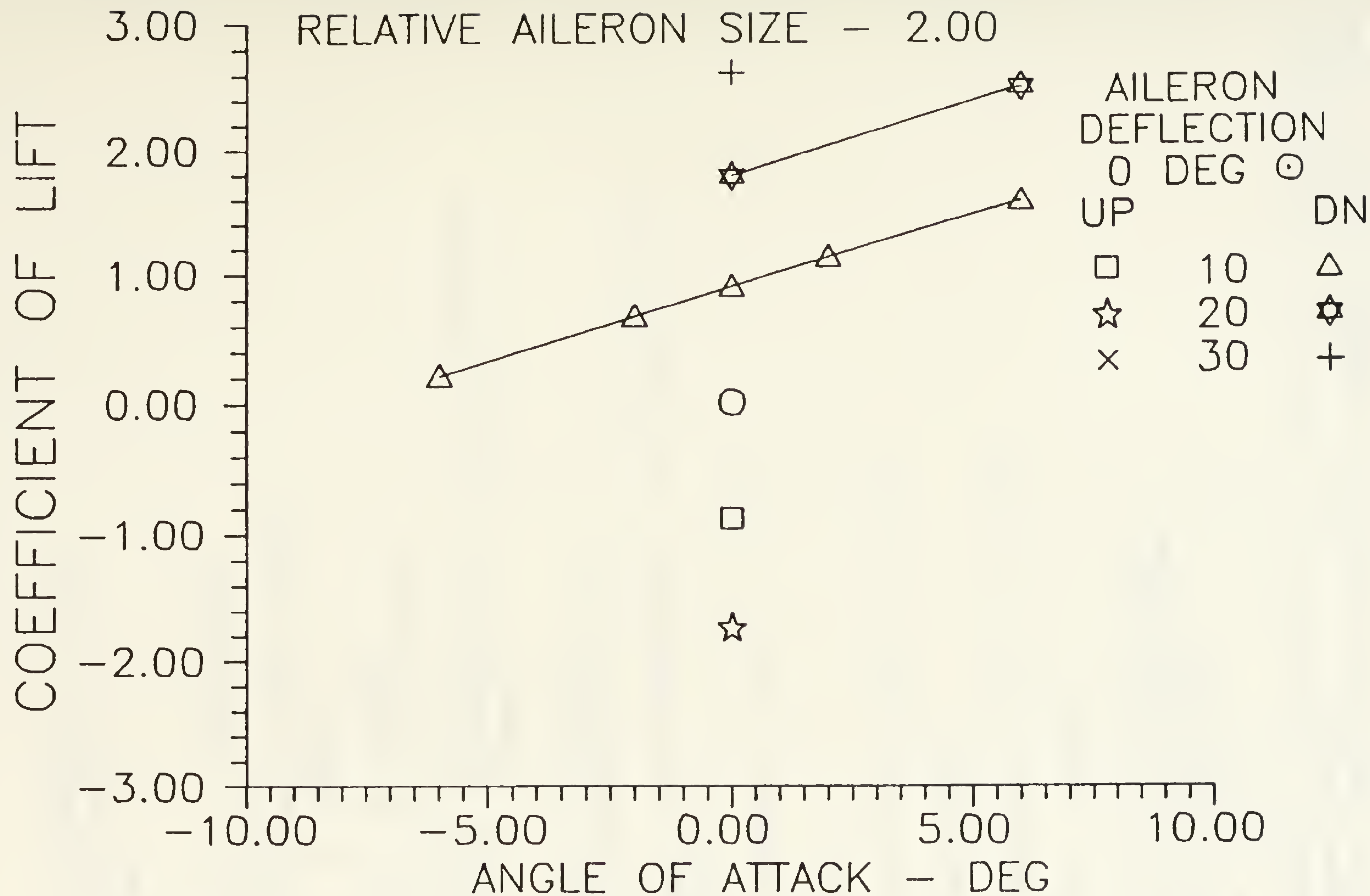

Figure 34
Effect of Angle of Attack

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