AE-74-1054-1

Investigation of the Kline-Fogleman Airfoil Section for Rotor Blade Applications

Semi-Annual Report

May 1 to November 30, 1974

by

Edward Lumsdaine

William S. Johnson

Lynn M. Fletcher

Judith E. Peach

THE UNIVERSITY OF TENNESSEE

Knoxville, Tennessee

(NASA-CR-141282) INVESTIGATION OF THE KLINE-FOGLEMAN AIRFOIL SECTION FOR ROTOR BLADE APPLICATIONS Semiannual Report, 1 May - 30 Nov. 1974 (Tennessee Univ.) 26 p HC $3.75 CSCL 01B G3/02

N75-14714

Unclas

06504

AE-74-1054-1

Investigation of the Kline-Fogleman Airfoil Section for Rotor Blade Applications

Semi-Annual Report

May 1 to November 30, 1974

by

Edward Lumsdaine
William S. Johnson
Lynn M. Fletcher
Judith E. Peach

Investigation Conducted
for the
National Aeronautics and Space Administration
under
Research Grant NSG 1054

December 15, 1974

ABSTRACT

Because of the sweeping claims made by Kline and Fogelman [1,2,3] (and the resulting national publicity) for a new wedgeshaped airfoil with a sharp leading edge and a spanwise step discovered in paper model flights, parametric wind-tunnel tests were conducted on this airfoil to determine its aerodynamic performance. The airfoil was tested with variations of the following parameters: Reynolds number, step location, step shape, apex angle, and with the step on either the upper or lower surface. These results are compared with a flat plate and with wedge airfoils (without step) with the same aspect ratio. A standard NACA 65-(10)10 airfoil as well as two delta wings were also tested. Water table tests were conducted for flow visualization; these results show that the flow separates from the upper surface at low angles of attack which is typical of thin airfoils and flat plates (leading edge separation).

The wind tunnel results show that for this new airfoil the lift/drag ratio is lower than for the flat plate, and the pressure data show that the airfoil derives its lift the same way as the inclined flat plate. This airfoil offers no discernable advantages over the conventional airfoil. The observed stability of the paper model (with high swept back angle) is primarily due to the sharp leading edge vortex lift phenomenon. Thin airfoils operating at low Reynolds numbers exhibit similar stability characteristics.

INTRODUCTION

The Kline-Fogelman wing first caught the attention of one of the authors in a Time Magazine science section article [1]. The claims in that article include one made by Kline (an advertising art director) of having somehow violated Bernoulli's principle with an airfoil discovered accidentally while flying paper model planes. The article further claimed that Kline had "inadvertently stumbled on a whole new field of aerodynamics."

It is easy to dismiss these claims as far-fetched since Bernoulli's principle can be derived from conservation of energy, and thus violation of this principle could be included in the category of "perpetual motion machines." Curiously, a great deal of favorable national publicity has been given to this airfoil[2], and a patent was issued[3]. Recently, plastic models of this plane have appeared in department stores, with the same claims. After observing a demonstration, Aeronautics Professor John Nicolaides of the University of Notre Dame, was quoted as being a "believer" in the Kline-Fogelman plane[1].

Figure 1 shows a chordwise section of the Kline-Fogelman airfoil. The claims in the patent include the sharp leading edge, straight upper and lower surfaces, and the step. In looking at this model it appears that the stability is derived from its sharp leading edge (vortex lift) and, at low Reynolds numbers leading edge separation is known to be very stable. The step appears to serve only to increase the drag at low angles of attack. It is also known that the lift/drag ratio for this type of stable delta wing is quite low (4,5,6).

Figure 1 Kline-Fogleman Airfoil Section

In a private discussion, Mr. Edward C. Polhamus of Langley Research Center, who is well-known in the study of vortex lift from delta wing airfoils, revealed that he had made a preliminary study of the Kline-Fogelman airfoil and concluded that the airfoil offers no particular advantage over conventional airfoils.

Near the end of the test program reported herein, results were published of recent tests conducted on this airfoil by Messrs. Delaurier and Harris of Battelle[7]. The results presented here are in agreement with their findings though much more extensive.

ACKNOWLEDGEMENT: This study was made possible through a summer work program for undergraduate minority and women engineering students sponsored by NASA-Langley. Dr. Eugene Hammond of NASA spent many hours assisting in the preparation of these tests; his efforts are greatly appreciated.

EXPERIMENTAL SETUP

A. Wind Tunnel and Instrumentation

The wind tunnel was of the standard open type and Figure 2 shows the test section with model no. 12 mounted on the balance. The balance incorporates strain gages to measure lift and drag up to a maximum of 2 lbf. The balance was equipped with a d-c drive motor for remotely varying the angle of attack and a potentiometer for angle readout. In an effort to produce two-dimensional flow, plates were employed at the two ends of the airfoil. However, the top plate was ineffective due to the clearance which was necessary for free movement of the airfoil. Removal of the top plate had no discernable effect on the results.

Figure 3 shows the instruments employed in the study. Lift, drag and angle of attack were read out on digital voltmeters while test section pressures were measured with a differential transducer and read on a B-IV type output device. The schematic of this instrumentation hookup is shown in Fig. 4. The static pressure distribution over selected models was read out on an inclined manometer. A check test was conducted at The University of Tennessee using a 50 pound balance and an airfoil having a 16 inch span and a 4 inch chord. The results of this test were in good agreement with those reported herein.

A total of 14 models were tested in the wind tunnel. Figures 5 and 6 show 10 of the 14 tested. Table I gives a summary of the geometric parameters of each model.

B. Water Table

Flow visualization using hydrogen bubbles was employed with a standard 48 in. x 18 in. Scott-Armfield water table, Model 9093. Comparisons were made between a Kline Fogleman airfoil with a 20° apex angle and a flat plate.

C. Test Procedure

For each model tested, lift and drag were determined as a function of angle of attack for angles from 0° to 360°. This produced data with the step on both the upper surface and lower surface in addition to other data not reported herein. These data were taken for tunnel dynamic pressures of 5, 10, 15 and 20 PSF which produced a Reynolds number range of 60,000 to 135,000. In addition, static pressures were determined over the airfoil surface at various angles of attack for models 8, 9 and 12 which were equipped with pressure taps.

DISCUSSION OF RESULTS

Figure 7 shows the influence of Reynolds number. It appears that in a range of 60,000 to 135,000 the lift coefficient is not grossly affected by Reynolds number variation. The results of Delaurier and Harris (7) are for a Reynolds number of 20,000 which is representative of "paper airplane" conditions. The influence of step height as illustrated on Figure 8, shows that increasing the step height decreases the lift at high angles of attack. As the step height becomes smaller, the lift curve approaches that of a flat plate. Thus, it appears that the step merely decreased the lift. The effect of the step on drag can be observed in Figure 9 which shows that the step acts to increase the drag.

If the airfoil is turned upside down (step up position) both C_L and C_L/C_D increase significantly as shown on Figures 10 and 11. This is in agreement with some preliminary measurements by Nicolaides (8). If an airfoil must operate continuously at an angle of attack higher than 20 degrees, the upside-down Kline-Fogleman airfoil with a fairly thick step (approximately 0.25 chord) appears to have an advantage with a higher C_L and a higher C_L/C_D than a flat plate or the NACA airfoil. This achievement of maximum lift at high angles of attack is typical of airfoils which derive their lift from leading-edge vortex phenomena.

Figures 12 and 13 point out the influence of step location (1/4 chord, 1/2 chord and without step). Moving the step forward increases the lift at higher angles of attack but decreases lift at lower angles of attack. The lift/drag ratio of these three airfoils remained about the same indicating that moving the step to increase lift would produce a corresponding drag increase. Some tests were conducted with an open slot. These results are not presented herein, but are substantially the same as with the solid airfoils.

Results from a delta wing with a 30 degree taper are shown on Figures 14 and 15. Comparison between the stepped delta model and the flat plate delta model show the same behavior as was found in the rectangular planform models.

Figures 16 and 17 show photos of the vortex patterns around a flat plate and a stepped airfoil at approximately the same angles of attack. It is quite evident that the leading edge separation and overall flow patterns of these two shapes are quite similar.

CONCLUSIONS

From the scope of this test program it can be concluded that the stepped airfoil offers little or no advantages over the conventional airfoil or flat plate, and in most configurations is decidedly inferior in terms of both lift and lift/drag ratio. Tests involving variations in the step geometry (location, size and shape) indicate quite conclusively that the lift is primarily a leading edge phenomenon which reaches a maximum when the step is not present. When the stepped airfoil is turned upside down (with the step on top of the airfoil) there is a marked increase in both lift and lift/drag ratio but these are still below the levels for conventional airfoils except at very large angles of attack. As noted in Reference 7, the pitching moments of this type airfoil tend to be slightly positive, which may have advantages in some applications.

REFERENCES

1. "The Paper Plane Caper", Time, April 2, 1973, pp. 51-52.

2. CBS Broadcast "60 Minutes", June 29, 1973.

3. U.S. Patent No. 3,706,430, December 19, 1972.

4. Polhamus, E.C., "A Concept of the Vortex Lift of Sharp-Edged Delta Wings Based on A Leading-Edge-Suction Analogy", NASA TN-D-3767, December 1966.

5. Brown, C.E. and Michael, W.H., "On Slender Delta Wings with Leading Edge Separation", NACA TN 3430, 1955.

6. McCullough, G.B. and Gault, D.E., "Examples of Three Representative Types of Airfoil-Section Stall at Low Speed", NACA TN 2502, September 1951.

7. DeLaurier, J.D. and Harris, J.M., "An Experimental Investigation of the Aerodynamic Characteristics of Stepped-Wedge Airfoils at Low Speeds", AIAA Paper 74-1015, 1974.

8. Nicolaides, J.D., Communication to Langley Research Center, April 11, 1973.

Figure 2 - Test Section with Model No. 12

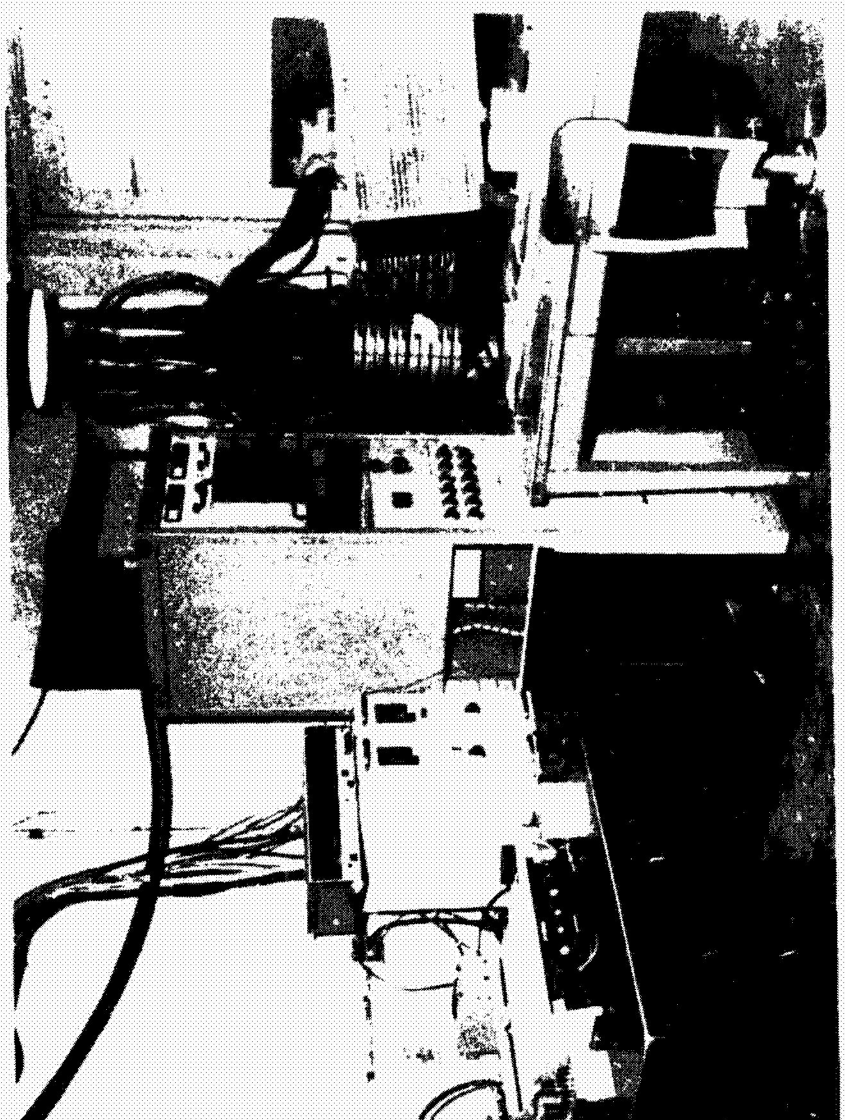


Figure 3 - Instrumentation

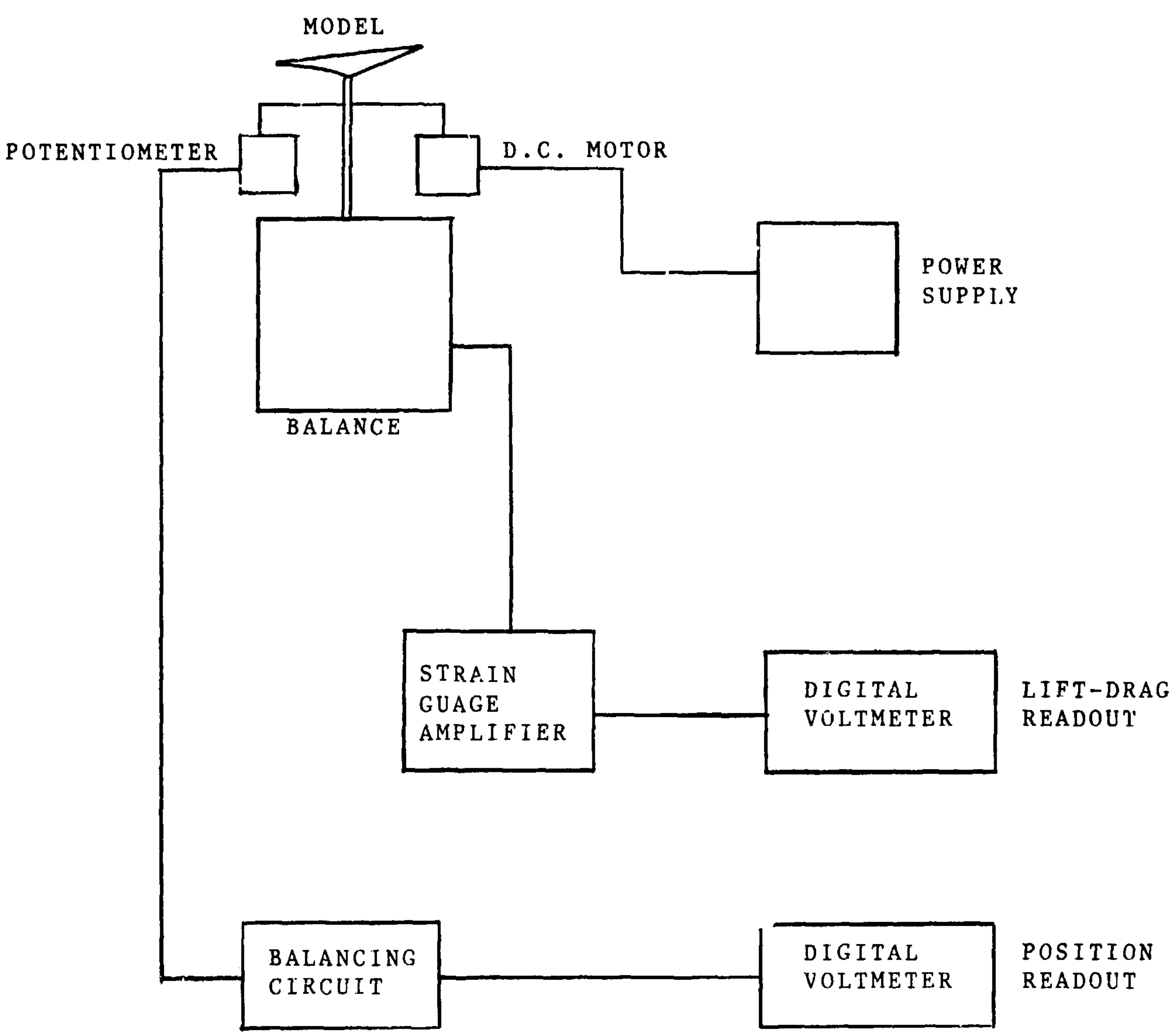


FIGURE 4 - INSTRUMENTATION HOOKUP

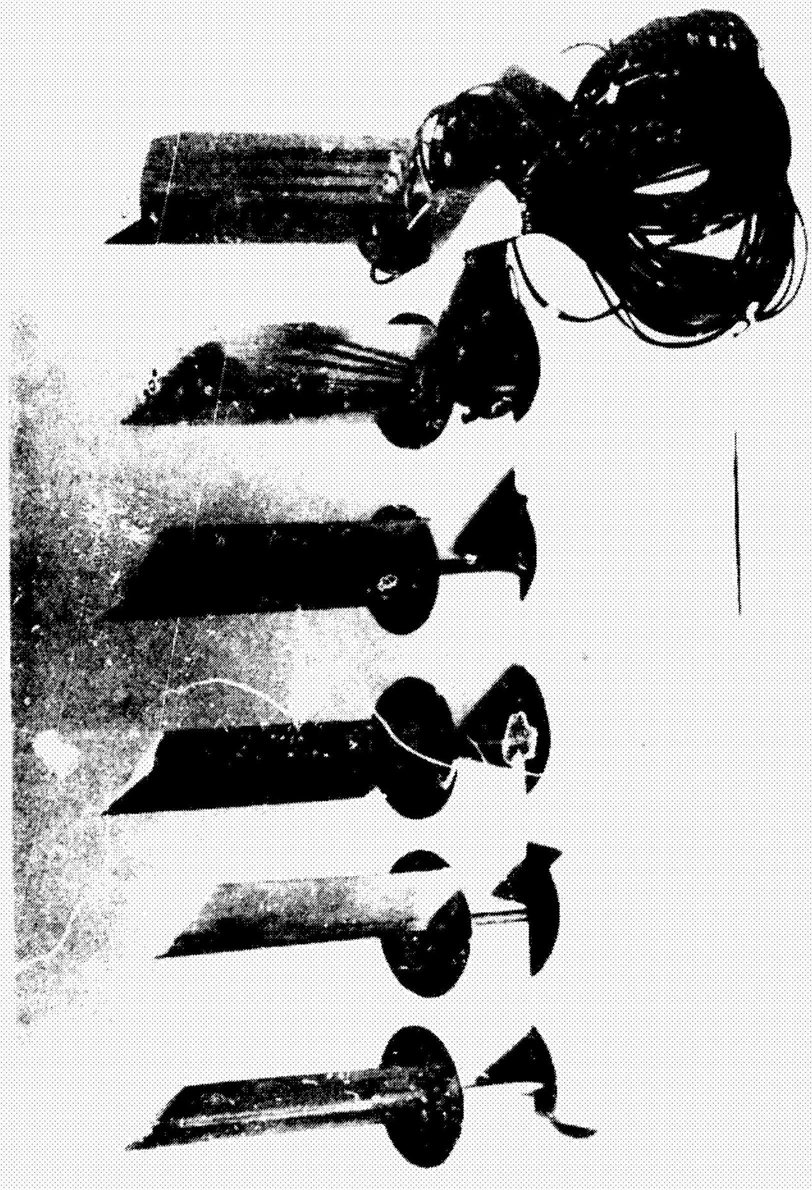


Figure 5 - Test Models

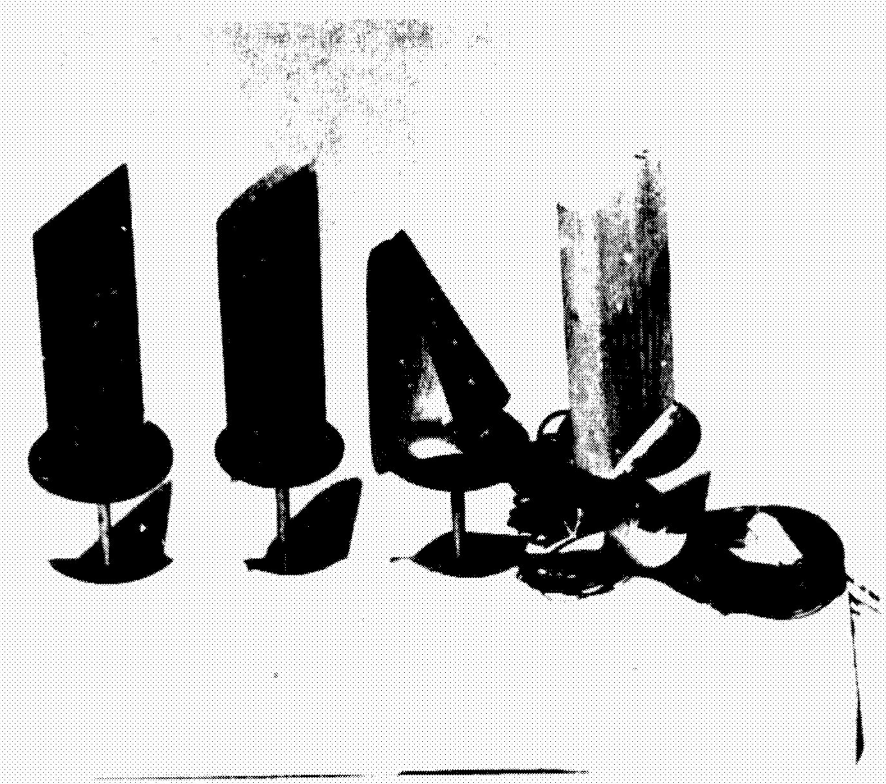
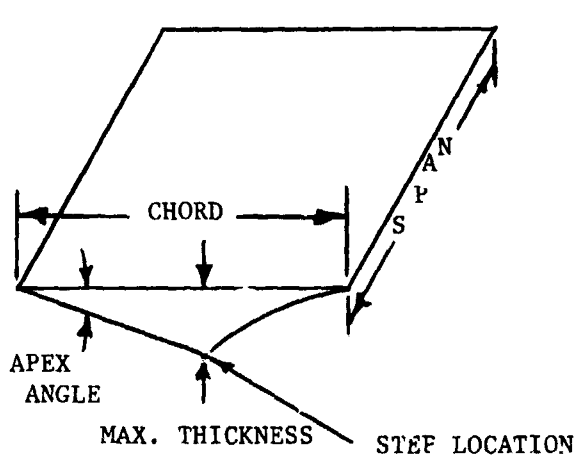


Figure 6 - Test Models

TABLE I

MODEL NO.	APEX ANGLE	$\frac{t_{max}}{C}$	STEP LOCATION	TAPER ANGLE	REMARKS
1*	--	.024	--	--	FLAT PLATE
2	--	.157	--	--	STANDARD NACA 65-(10)10 AIRFOIL
3	--	.164	C/2	--	STANDARD NACA 65-(10)10 WITH FOWLER FLAP REMOVED
4	10°	.088	C/2	--	--
5	10°	.128	3C/4	--	--
6	10°	.089	C/2	--	SHARP-STEP
7	20°	.105	C/4	--	--
8	20°	.318	--	--	SYMMETRICAL WEDGE WITH PRESSURE TAPS AT S/2
9	22°	.197	C/2	--	PRESSURE TAPS AT S/2
10	15°	.144	C/2	--	HOLLOW SLOT
11	15°	.207	3C/4	--	HOLLOW SLOT
12	30°	.260	C/2	--	PRESSURE TAPS AT S/2
13	--	.022	--	26°	DELTA FLAT PLATE
14	20°	.186 AT ROOT	C/2	26°	TAPERED DELTA WING NO SWEEP

* ALL RECTANGULAR AIRFOILS HAVE CHORD = 2 INCHES AND SPAN = 4.5 INCHES



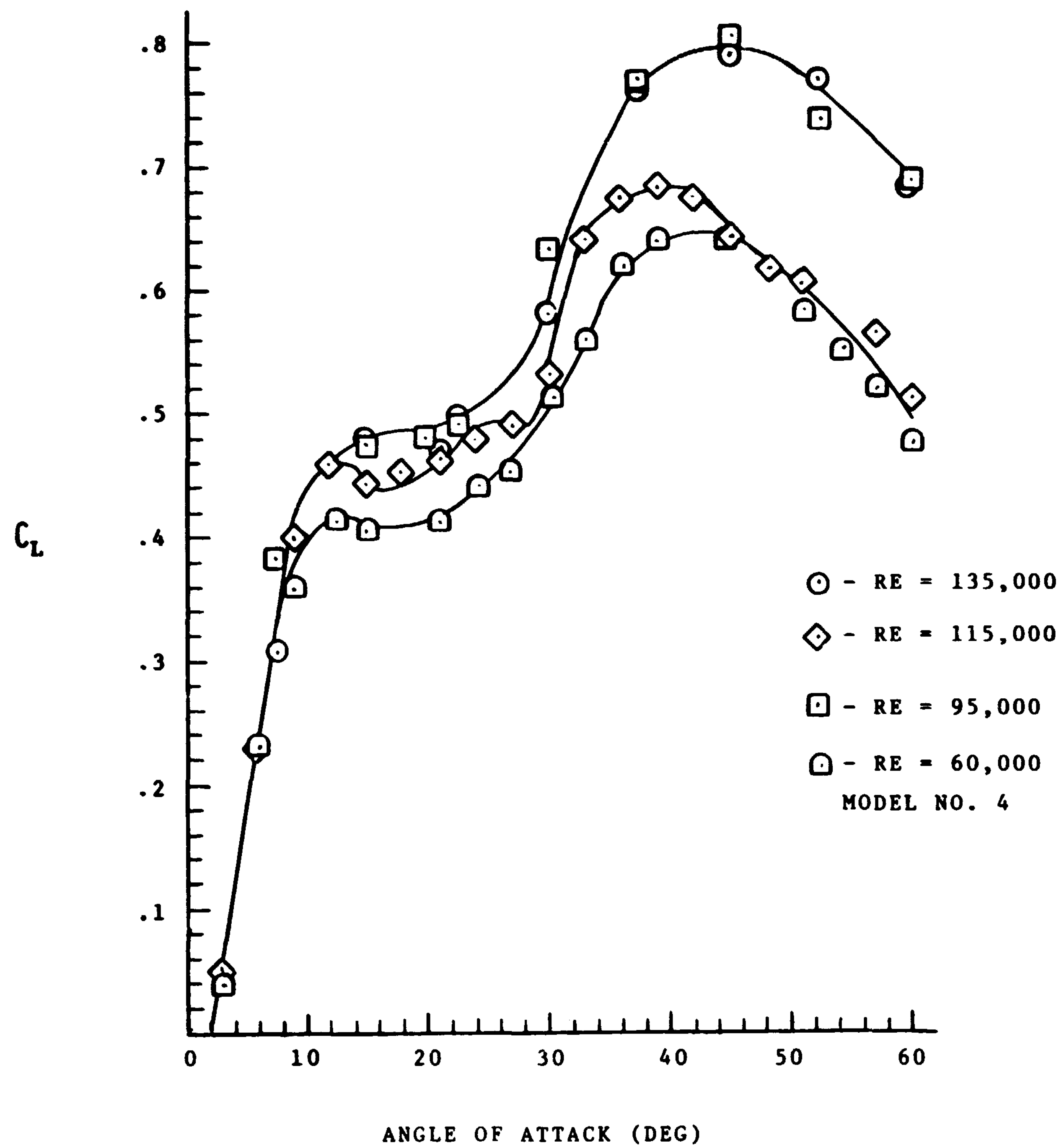


Figure 7 - C_L Versus Angle of Attack - Effect of Reynolds Number

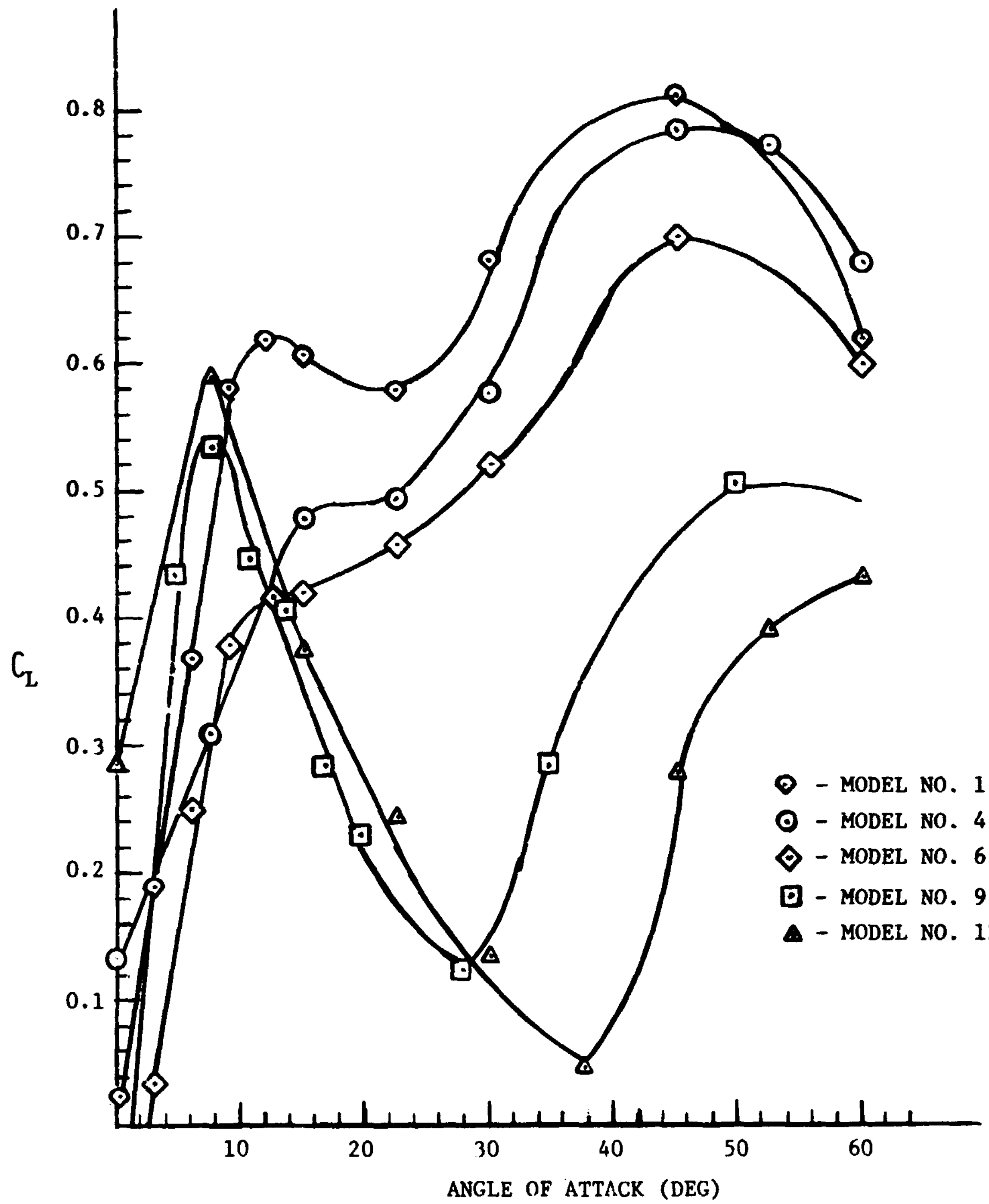


Figure 8 - C_L Versus Angle of Attack - Effect of Step Height

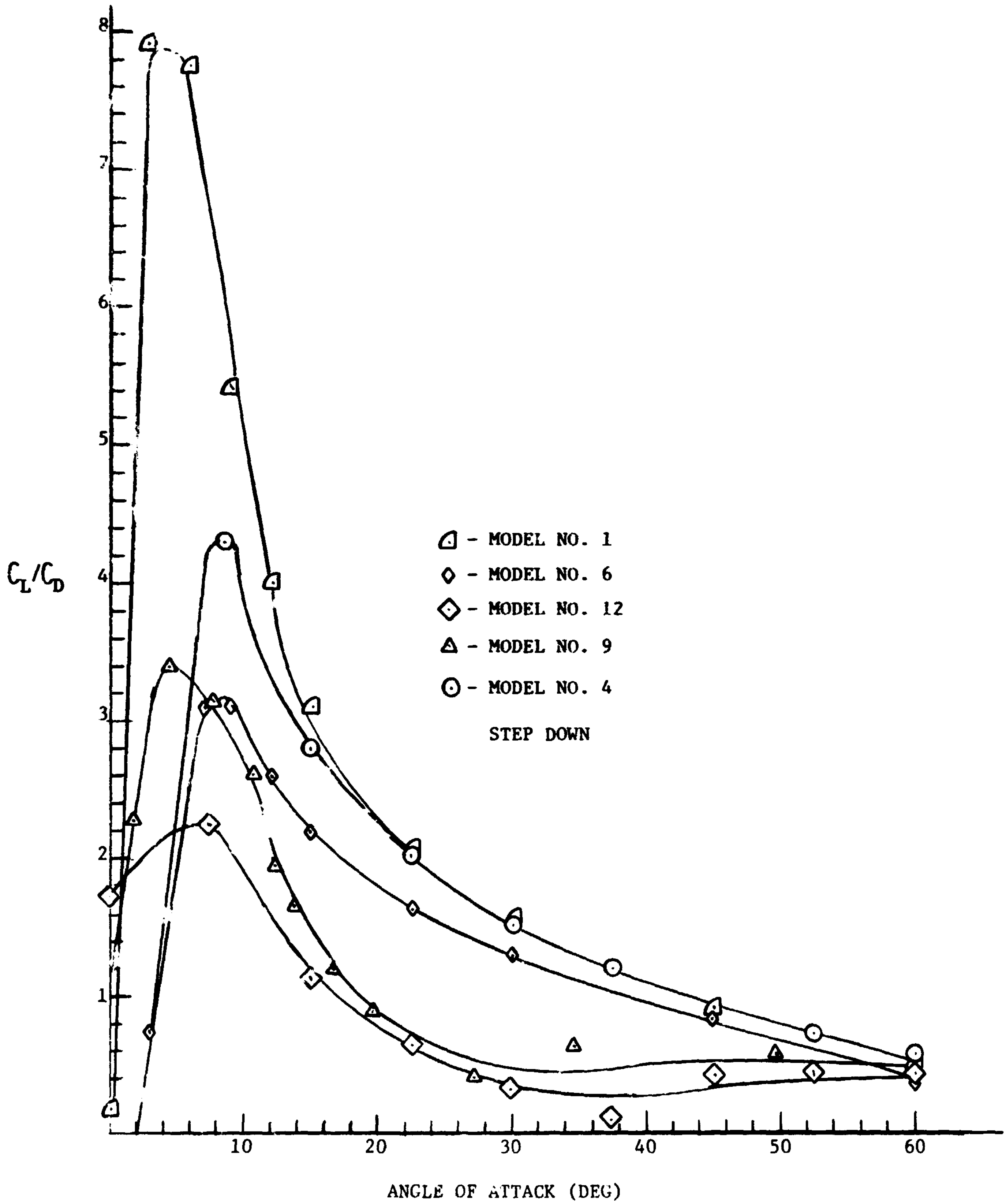


Figure 9 - C_L/C_D Versus Angle of Attack - Step on Bottom

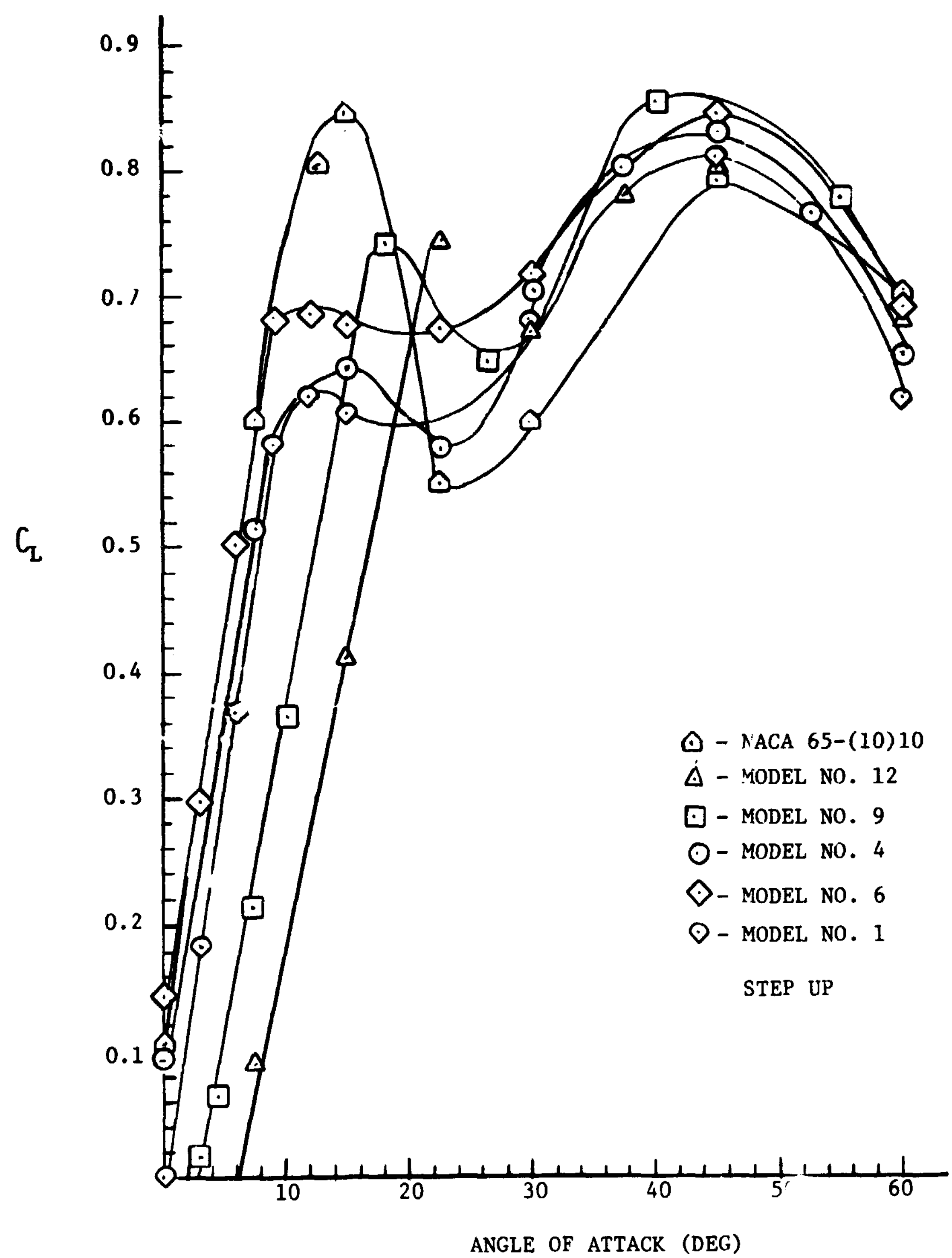


Figure 10 - C_L Versus Angle of Attack - Step on Top

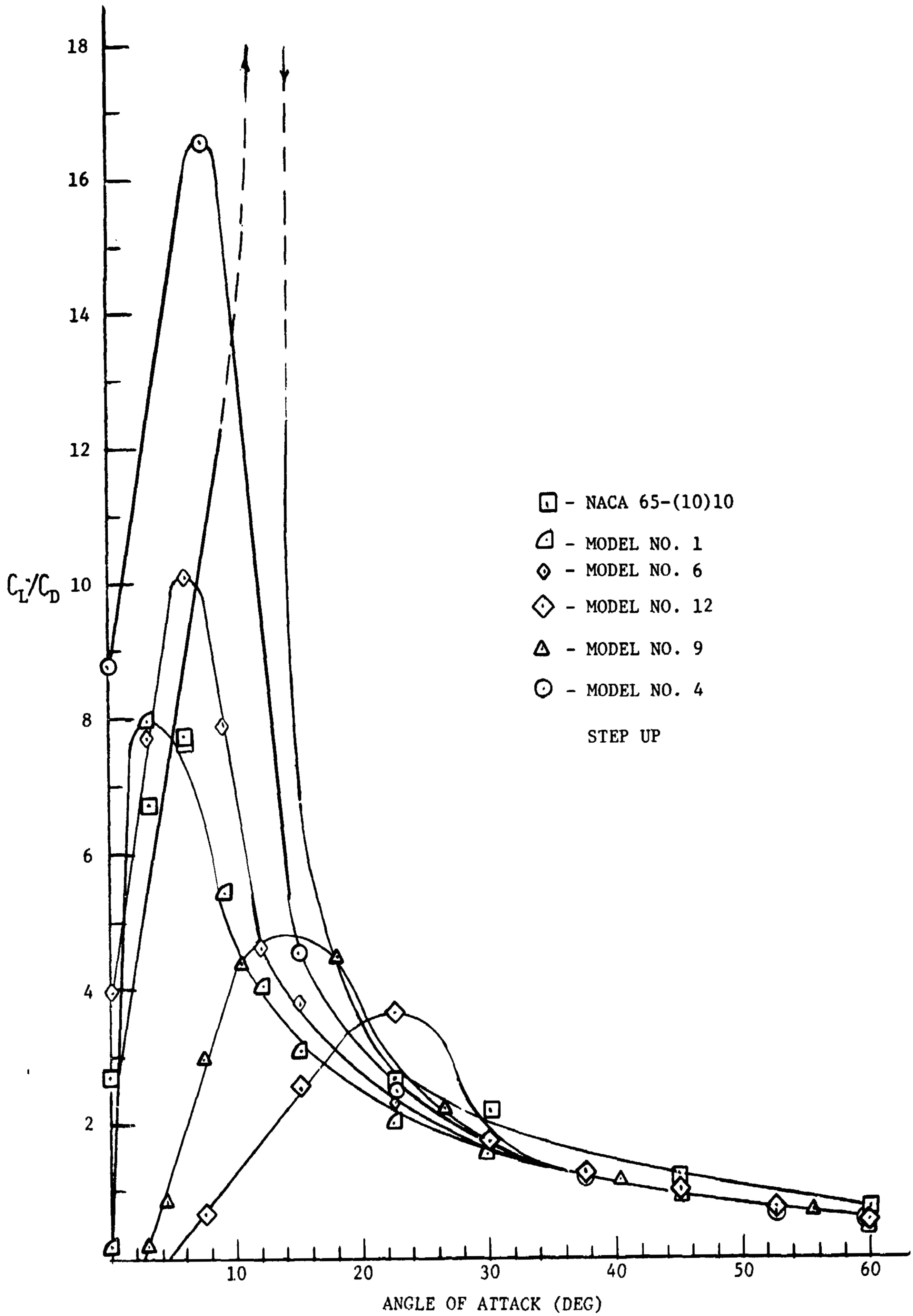


Figure 11 - C_L/C_D Versus Angle of Attack - Step on Top

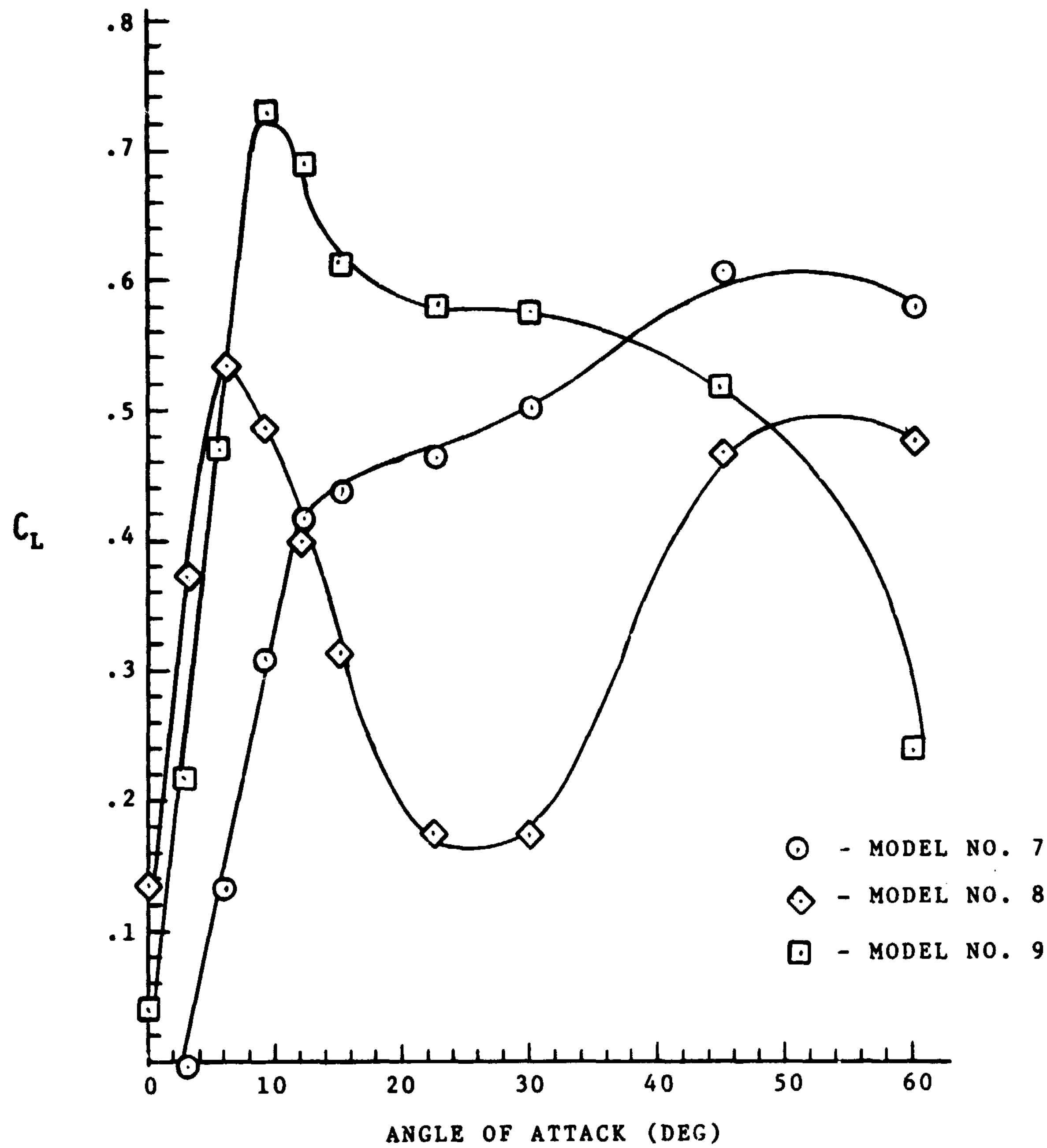


Figure 12 - C_L Versus Angle of Attack - Effect of Step Location

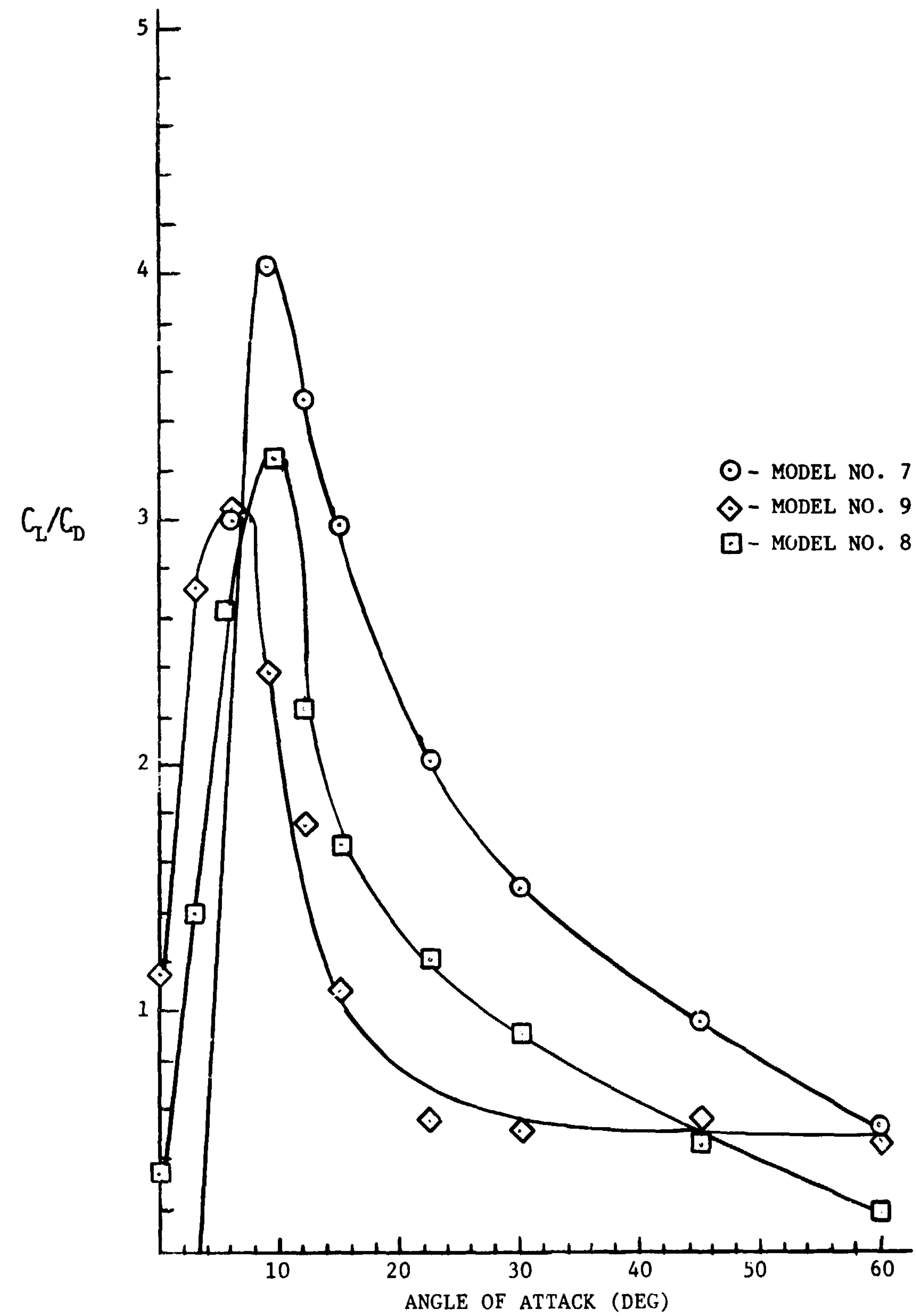


Figure 13 - C_L/C_D Versus Angle of Attack - Effect of Step Location

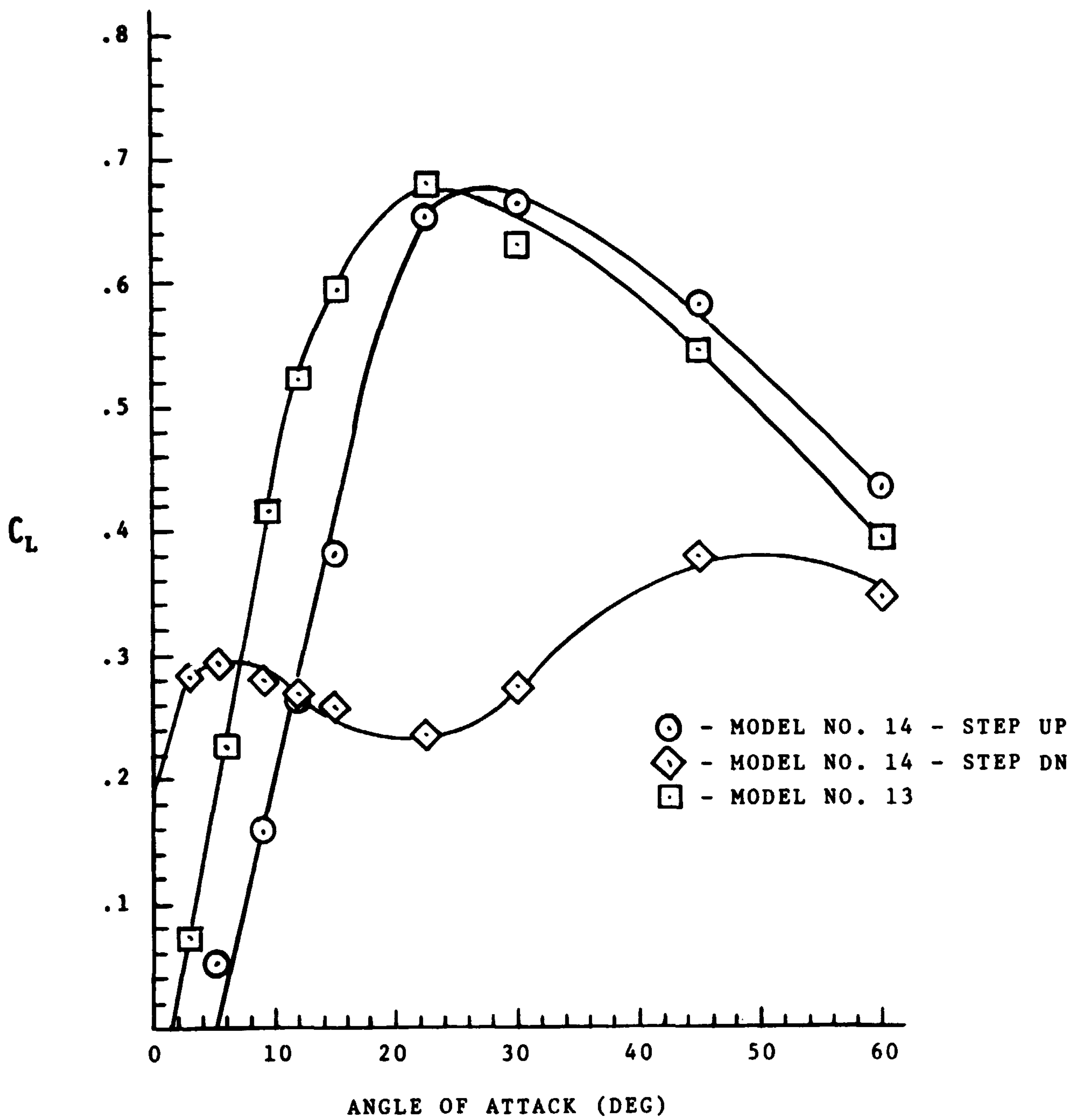


Figure 14 - C_L Versus Angle of Attack - Effect of Step

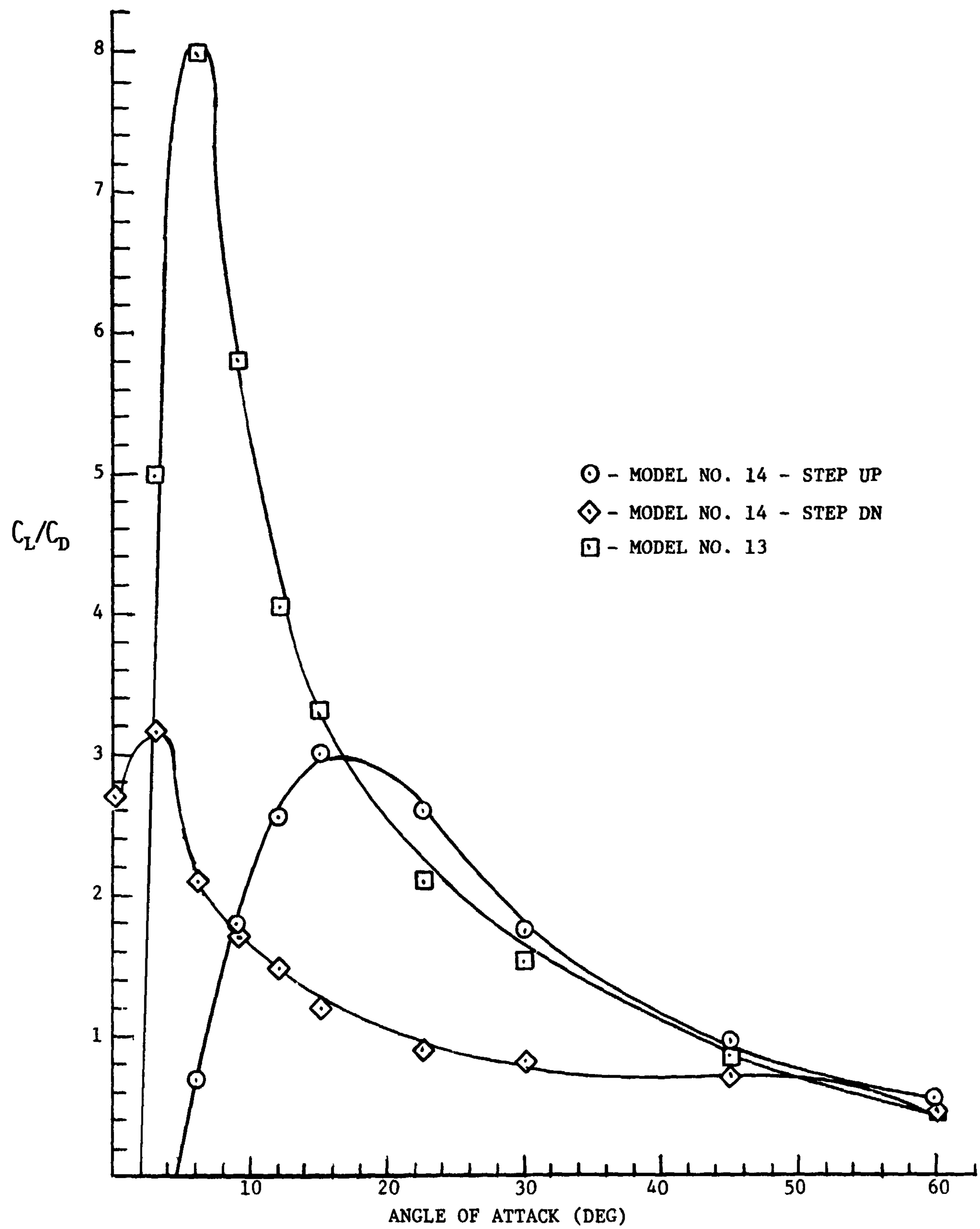


Figure 15 - C_L/C_D Versus Angle of Attack - Effect of Step

Figure 16 - Flow Visualization Results Using Hydrogen Bubbles

Figure 17 - Flow Visualization Results Using Hydrogen Bubbles