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THE DEVELOPMENT OF EFFICIENT TRAWL BOARDS USING HYDRODYNAMIC MODEL TESTS

by

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SUMMARY

A major source of trawl system inefficiency is the poor hydrodynamic qualities of the trawl boards commonly used by U.S. fishermen. Initial studies had shown that, through the use of hydrodynamic principles, significant improvements could be realized. To optimize trawl board design parameters a systematic series of model tests was needed.

A family of trawl board configurations was developed consisting of 24 different models. All designs were low aspect ratio, untapered, asymetric foils made up of flat or constant radius surfaces. Variations of sectional shape, aspect ratio, planform and slot location were studied. Water tunnel tests were conducted at Reynolds Numbers of 1×10^6 with the model in contact with a splitter plate to simulate the hydrodynamic effect of trawl board contact with the seabed. Angles of attack were varied from -20 to +50 degrees. Lift, drag and moment data was obtained and reduced to coefficient form.

The test results are presented graphically as C_L and C_D versus angle of attack. The effect of parameter changes is discussed, the designs tested are evaluated in regard to their size requirement and resistance compared with the existing trawl boards. Implications beyond the configurations tested are made and a rough analysis of the economic effect of trawl board efficiency is presented.

All models tested were found superior hydrodynamically to the board presently used. The improved lift coefficients predicted by these tests would allow boards up to 37% smaller. Reduced drag coefficients and the smaller size would provide as much as a 66% decrease in board resistance.

In situ testing of prototype boards on commercial trawlers partially substanciated these predictions. The prototype boards were found less stable than conventional trawl boards during vessel turns and under cross tide conditions. Underwater video observations revealed that when the course made good by the trawl system over the bottom differed from the direction of tow by an angle greater than the trawl door's angle of attack, instability resulted. The prototype trawl boards, with low optimum angle of attack were more susceptible to such conditions.

With knowledge of tidal current conditions proper directions of tow can be established to minimize or eliminate these problems. The adoption of such a low drag trawl board would have a significant effect on the economics and productivity of trawling. Fuel savings of up to 20% or increases in catch size of 34% seem feasible.

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ACKNOWLEDGEMENTS

The initial hydrodynamic studies and the subsequent field testing were funded by the M.I.T. Sea Grant College Program which is supported by the Office of Sea Grant in the National Oceanic and Atmospheric Administration through grant number 04-7-158-44079. The parametric hydrodynamic model studies were supported by the National Science Foundation through contract number NSF-C-APR77-19072. Sea Grant project # R/L-4

The underwater video observations during field testing was done in cooperation with the Marine Fisheries Program at the Massachusetts Maritime Academy. The efforts of Ronald Giovanni of Wharf Forging and Welding Co. during the prototype construction and modifying is also appreciated. Commercial tests aboard local trawlers were an important part of this research effort. The cooperation of Henry Klimm of the Capt. Bill V out of Woods Hole, Sammy Novello of the Vincie N. out of Gloucester and Peter Favazza of of the Everfree out of Gloucester was greatly appreciated.

INTRODUCTION

The Fishery Conservation and Management Act of 1976, or the 200 mile limit, has failed to yield the bonanza anticipated by the fishing industry. Management programs now have more control of fishing stocks but fishermen are still faced with stiff competition from imported fish and a significant portion of the stocks remain uneconomical to harvest. In addition, rising fuel costs have had a devastating effect on many segments of the industry. Trawling in particular is one of the most energy intensive methods of fish harvesting. Present trawlers burn nearly one pound of diesel fuel for every pound of fish landed. This staggering figure is partly due to the tendency of U.S. fishermen to land high priced, less abundant species, but is also due to a collection of inefficiencies in the trawl systems.

Present technology points to trawling as the most practical method for harvesting both demersal and mid-water fishes. Fish detection equipement aids greatly in the catching ability of a trawler, but the process is basically that of filtering the water to remove the fish of appropriate size.

The trawl net is towed behind the vessel by cables. The mouth of the net is kept open vertically by floats about the upper perimeter and weights about the lower perimeter. The horizontal mouth opening is maintained by the trawl boards. These devices are lifting surfaces set at an outward angle of attack to provide the required sidewards thrust.

Two major contributors to a trawler's inefficiency are the propulsion system and the trawl boards. Building trawlers with ducted and/or controllable pitch propellors or retrofitting these devices on existing vessels represents considerable investments for propulsion improvement. More efficient trawl boards are an economically attractive alternative for a boat owner seeking increased productivity and decreased fuel consumption.

The trawl boards (often referred to as trawl doors) in common use in the U.S. today have remained unchanged for many years. They are usually a flat wooden surface banded with steel, with a heavy steel shoe to resist abrasion. Trawl doors on a typical 80 foot New England trawler would be around 4 feet high, 8 feet long, and weigh 1000 pounds. Heretofore, they have proven adequate for the task and fishermen have tolerated the following shortcomings:

1) Excessive drag due to poor hydrodynamic qualities.

2) Inconsistent behavior resulting from slight variations in construction or wood quality.

3) High initial and maintenance costs.

The first of these is by far the most significant and represents the major problem addressed in this paper.

Inconsistent behavior can be alleviated through the use of materials with more constant physical properties. The buoyant effect of the wood adds to the stability of the boards while setting and retrieving, but wood becomes waterlogged with time, changing the weight and balance of the board. Even some new boards don't function properly due to wood anomalies. The use of all steel construction has, in some cases, improved the predictability of trawl boards.

The high initial and maintenance costs are due to the complicated configuration of currently used boards. Each board is composed of approximately 5 wooden planks, 32 major steel components and dozens of nuts and bolts. The assembly time is around three man days per pair, exclusive of the preliminary hot or cold forming of the steel parts. A new, simple design could decrease the fabrication costs considerably.

The expected life of a pair of trawl boards is from 2 to 5 years. Deterioration of or damage to the wood is usually the cause for replacement or rebuilding. The wear surfaces last less than a year and the boards are taken ashore for re-shoeing by the manufacturer. A desirable feature of a new board design would be shoes that are replaceable by the fisherman.

The problems of board behavior, durability and cost have been addressed to some extent by current board manufacturers. The V-form board, common on the west coast, is all steel for durability and designed to easily ride over bottom obstacles. The French oval board, which has been recently imported to the U.S. East Coast, is also built of steel and designed for ease of shoe replacement. Niether of these alternative trawl boards represents a significant improvement in hydrodynamic performance (1).

There is little relevant hydrodynamic testing in the literature to aid in determination of an optimum trawl board configuration. The hydrodynamic characteristics of existing boards with only minor variations of some parameters (2,3,4) are of little use in conceptual design. The low aspect ratio, asymetry, size limitations, and high angle of attack of trawl boards render most of the seemingly related tests on other hydrodynamic and aerodymanic lifting surfaces inappropriate. Of the tests which do fall within the operating realm of trawl boards (5,6,7), all are control or lifting surfaces under extreme conditions, i.e., conventional foils which are tested to high angles of attack to determine post-stall characteristics.

In earlier work by the author (8) a novel trawl board configuration composed of constant radii surfaces was designed (see figure 1). A model of this board was tested to determine its hydrodynamic characteristics and found significantly more efficient than the conventional type. The design is subject to a U.S. patent (9) and is being commercially produced by Wharf Forging and Welding of South Boston, Massachusetts. The results of the model tests are presented in Figure 2.

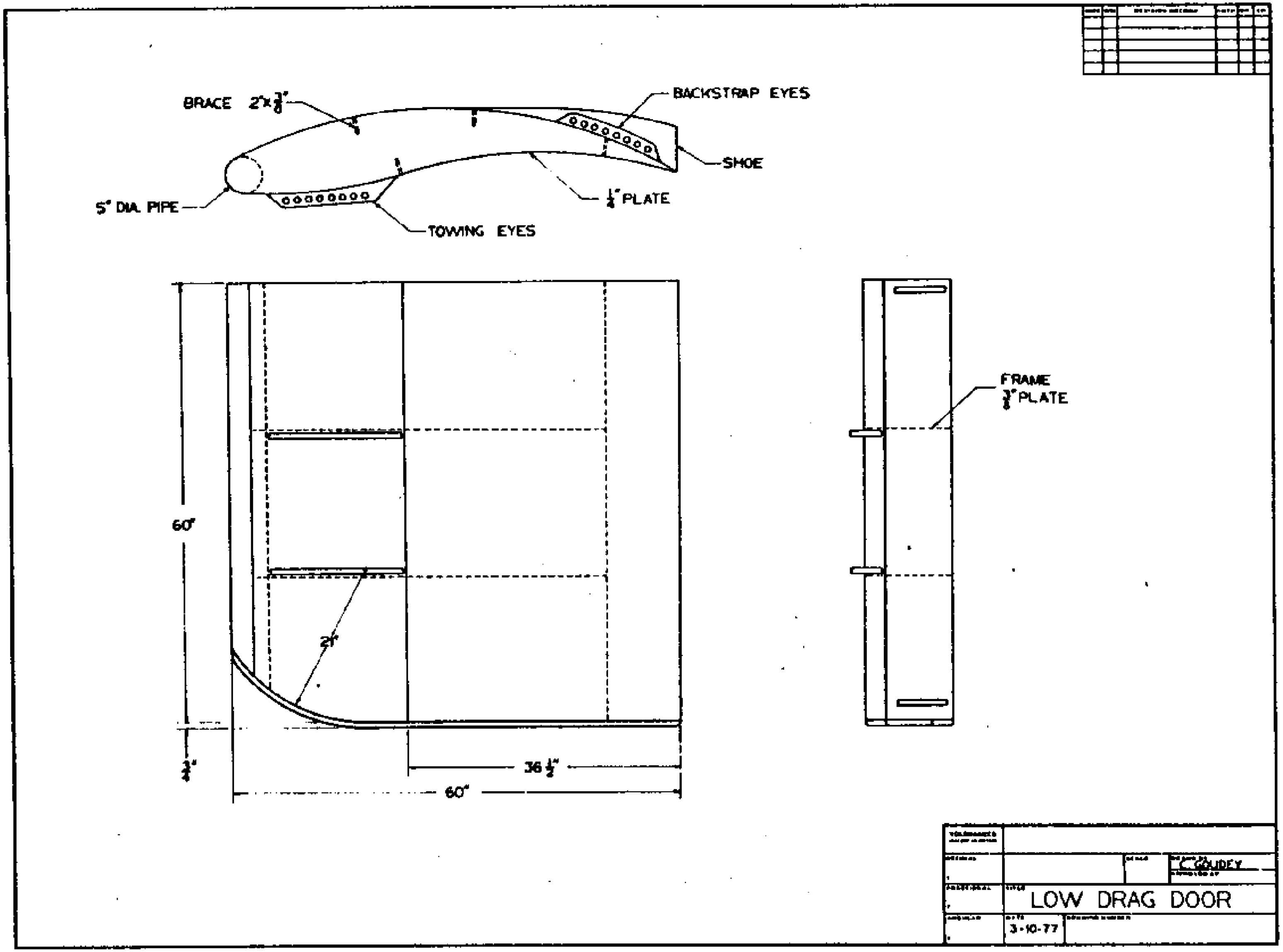


Figure 1. Prototype Sea Grant trawl board (Ref.8)

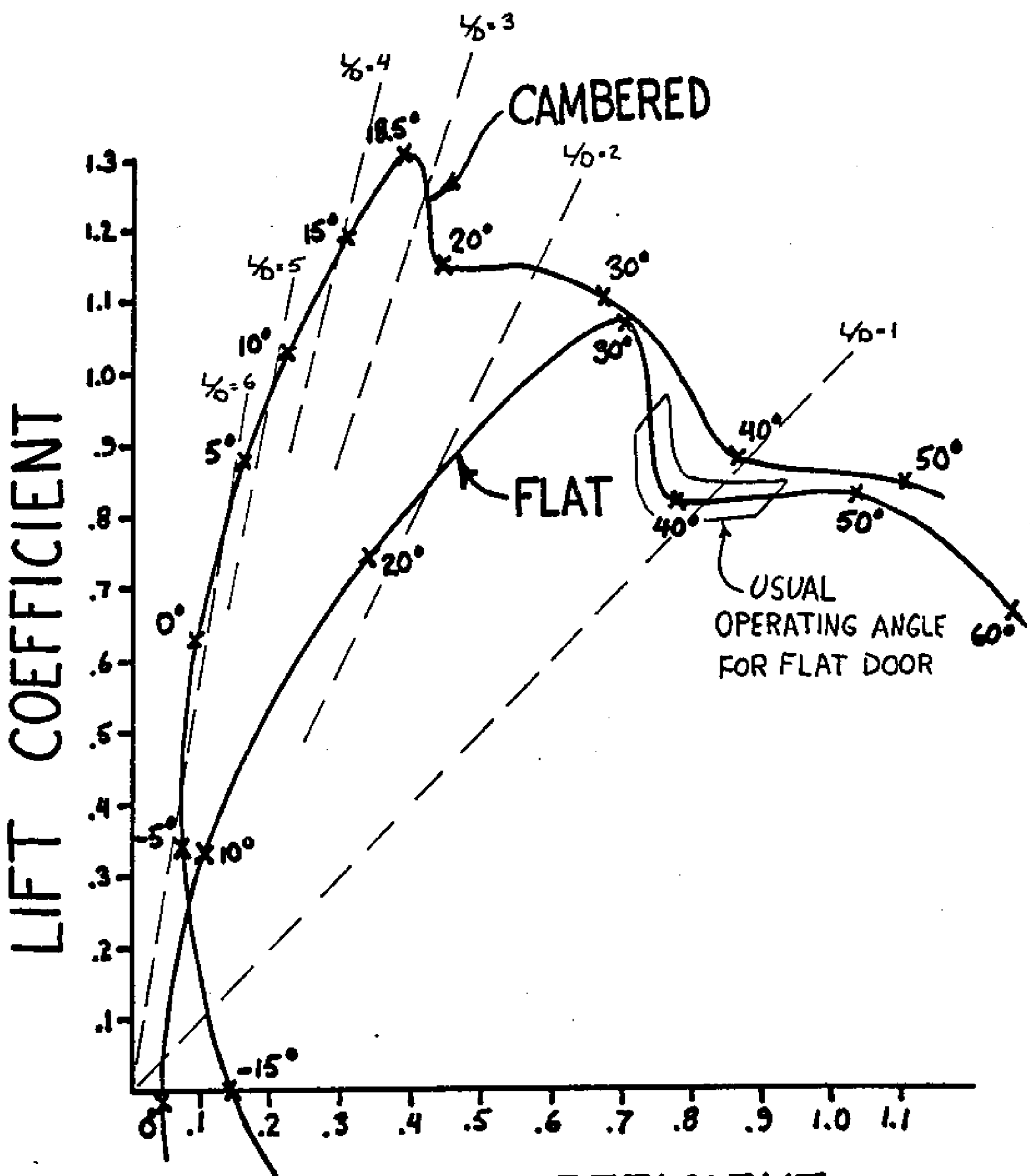


Figure 2. Hydrodynamic test results of Sea Grant model and flat trawl door model (Ref.8)

MODELS AND TEST FACILITIES

To further study the effects of various board parameters, a systematic series of trawl board shapes was developed based on the original Sea Grant sponsored design concept. These designs are shown in figures 3 to 5. This phase of research was supported by the National Science Foundation and is reported in reference 10 in detail.

The designs can be divided into four groups. The first group of four shapes (figure 3) is similar to the original Sea Grant trawl board and was designed to study the effects of changes in thickness and camber. Design D differs from the original only in thickness. Comparing its shape with the original, this change in thickness is achieved geometrically by moving the pressure side inflection point from the 40% chord position to the mid-chord position. In design A, this inflection point has been moved forward to the 30% position resulting in a thinner sectional shape.

Designs G and E represent variations in camber. The arc radii have been changed to 83 1/3% and 125% of chord length respectively. The inflection point has been adjusted in these models to maintain the same thickness as in the original design.

The second group (figure 4) consists of four designs with flat pressure surfaces. Models F and B are circular backed foils intended, in part, to determine the effect of leading edge radius variation. Models C and H are circular arcs in the forward part of the suction side, with the after part being a flat surface. These four models represent a simpler geometry than the original prototype and it seemed worthwhile to investigate their hydrodynamic properties. Considerable economies of manufacture could be realized if a trawl door of this type performed comparably to the more complex shapes considered.

The third group has two models of unrelated form. Model I is made up of circular arcs, however, unlike the original, the pressure surface is a single arc and the suction surface is a combination of two arcs of differing radii. The smaller radius arc (67% chord length) is forward and the larger radius arc (125% chord length) is aft, in keeping with practice in conventional hydrofoil design. Model J is of slightly simpler form with the suction surface a single arc of radius equal to the chord length. The nose radius is slightly greater, both to provide thickness comparable to the baseline (prototype) model and to provide sufficient stiffness in the trailing edge.

The fourth group (figure 5) has two designs included to determine the effect of slots on trawl door performance. Two configurations were used: Model K, with a mid-chord slot, and Model L with a slot located at 25% of chord length from the leading edge.

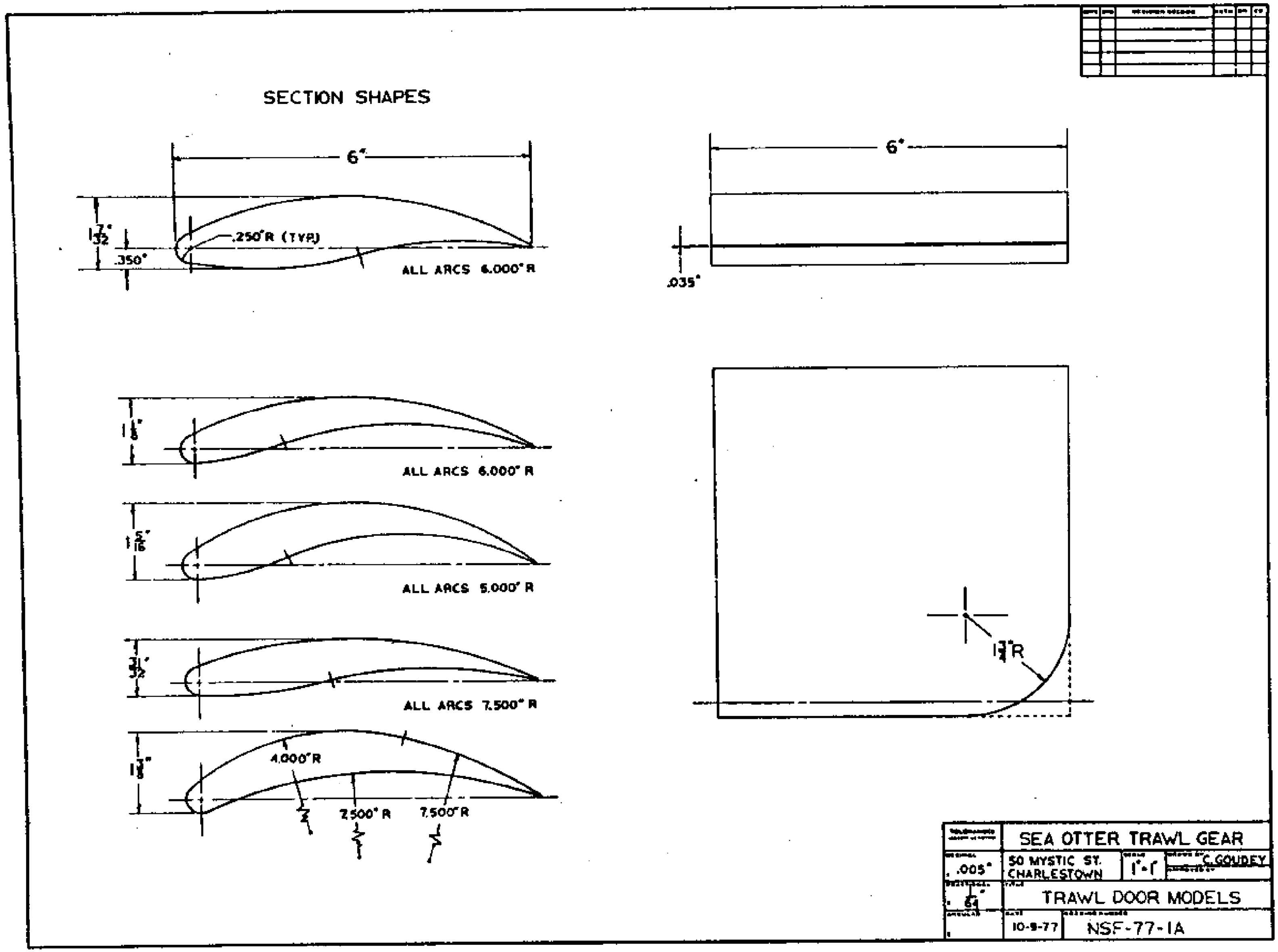


Figure 3. Trawl door models D, A, G, E and I

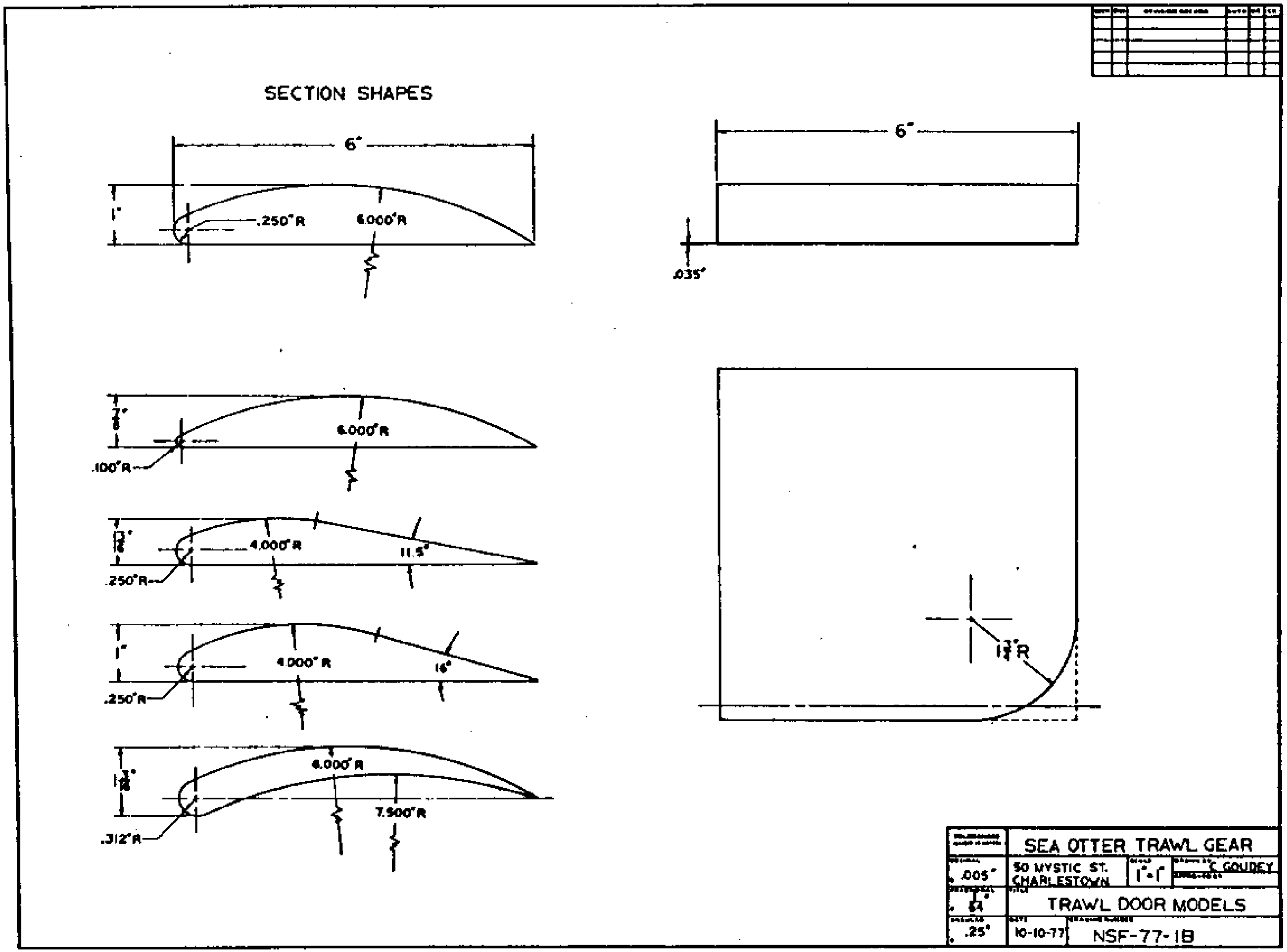


Figure 4. Trawl door models F, B, C, H and J

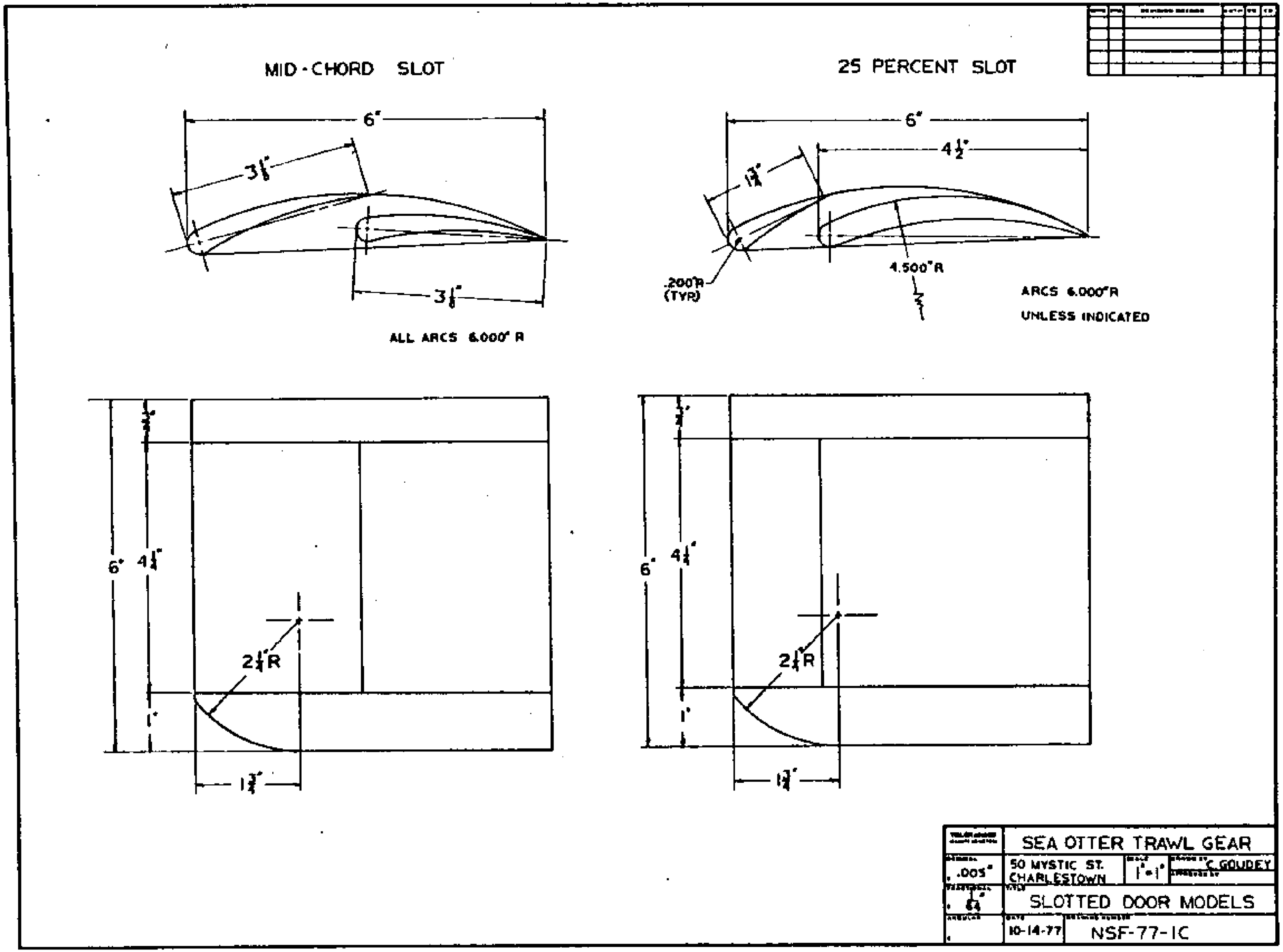


Figure 5. Slotted trawl door models K and L

The models were constructed for testing in M.I.T.'s variable pressure water tunnel. Model dimensions were as indicated in figures 3 to 5. This size is well suited to the 20" x 20" test section; yielding forces large enough for accurate load cell measurements, but not causing excessive blockage.

Models were constructed of 6061 aluminum, providing machinability corrosion resistance and adequate strength. Most of the foil surfaces were turned on a lathe. Six inch by eight inch plates of the required thickness were drilled and mounted to a right angle fixture. This was then mounted on a lathe face plate and accurately located for the internal or external cutting. Material which could not be removed in this manner was machined by milling or hand filed.

The models were then hand sanded to a 8-16μin. finish and cut to length. To facilitate mounting in the test section, the models were drilled and tapped in the edge corresponding to the shoe of the full size door. The forward part of this edge was then rounded off. The slotted models were assembled by welding the lower joint and providing recessed cap screws for the upper joint.

Later modifications to change aspect ratios were accomplished by band sawing off the upper portions of selected models. The planforms of the modified models are shown in figure 6.

The variable pressure water tunnel at M.I.T.'s Marine Hydrodynamics Laboratory is well suited to this type of experiment. The tunnel, shown in figures 7 and 8, was originally intended for marine propellor studies, but has been used for many other types of flow studies. Flow velocities of up to 30 feet per second in the test section are attainable. Pressure can be reduced for cavitation studies, however, due to the great operating depths, this is of no importance in trawl door design.

To simulate the flow characteristics of a trawl door in contact with the seabed, the test section was fitted with a splitter plate. This device, shown in figure 9, serves to remove the tunnel wall boundary layer and present an approximately uniform flow pattern at the foil location. As seen in the figure, the door model is mounted in an inverted position to a shaft passing through the splitter plate and top panel of the test section. These openings are properly sealed to prevent leakage and to transmit the loads experienced by the model to the dynamometer above.

The dynamometer used for these tests was designed for rudder, keel, and other three dimensional hydrofoil testing. Though capable of measuring six degrees of freedom, only lift, drag, and pitching moment were of interest.

Tunnel velocities were measured using a differential pressure manometer connected to taps located in the convergence ahead of the test section. Angle of attack was adjusted manually by rotating the dynamometer shaft.

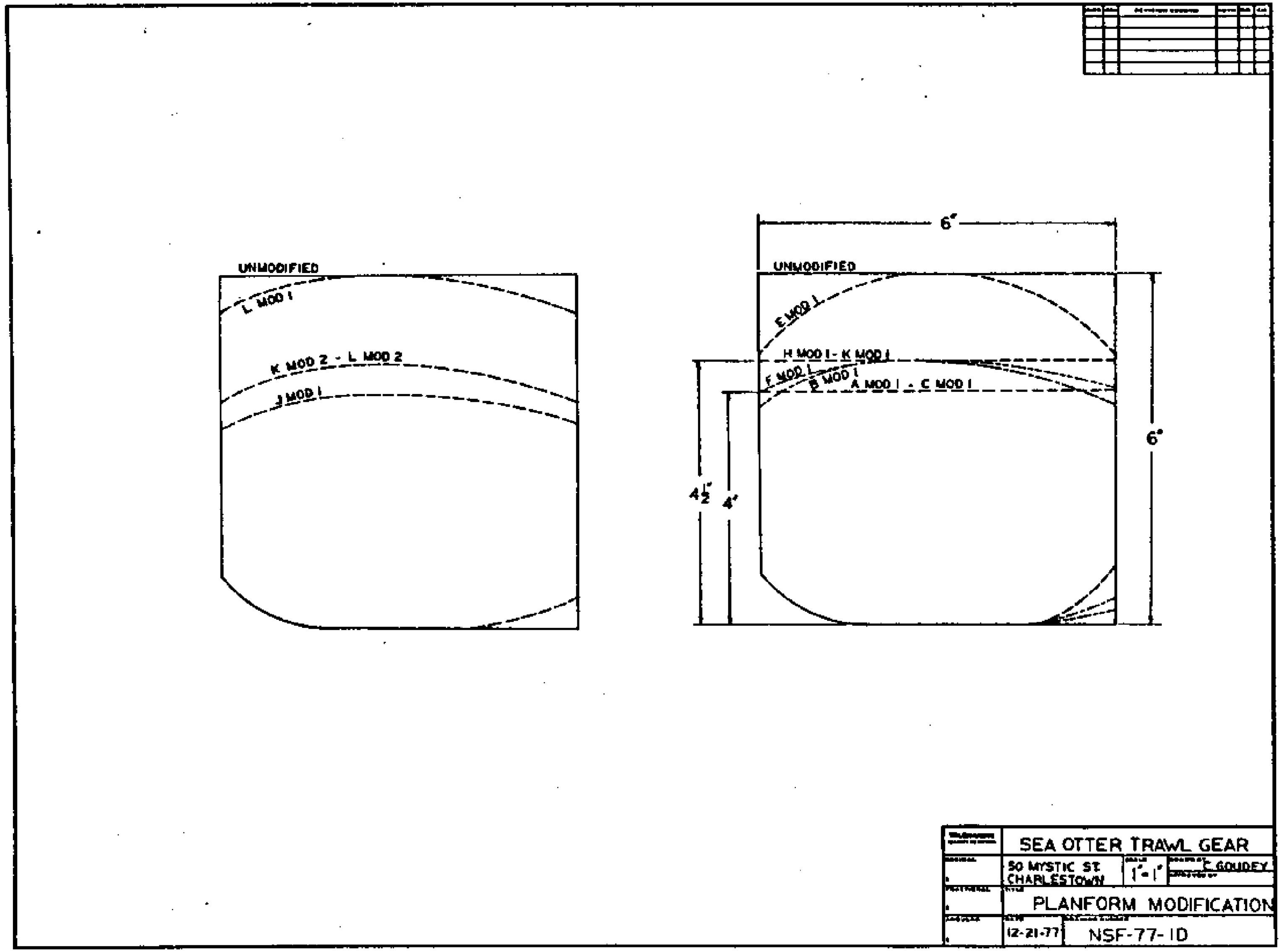


Figure 6. Planform Modifications

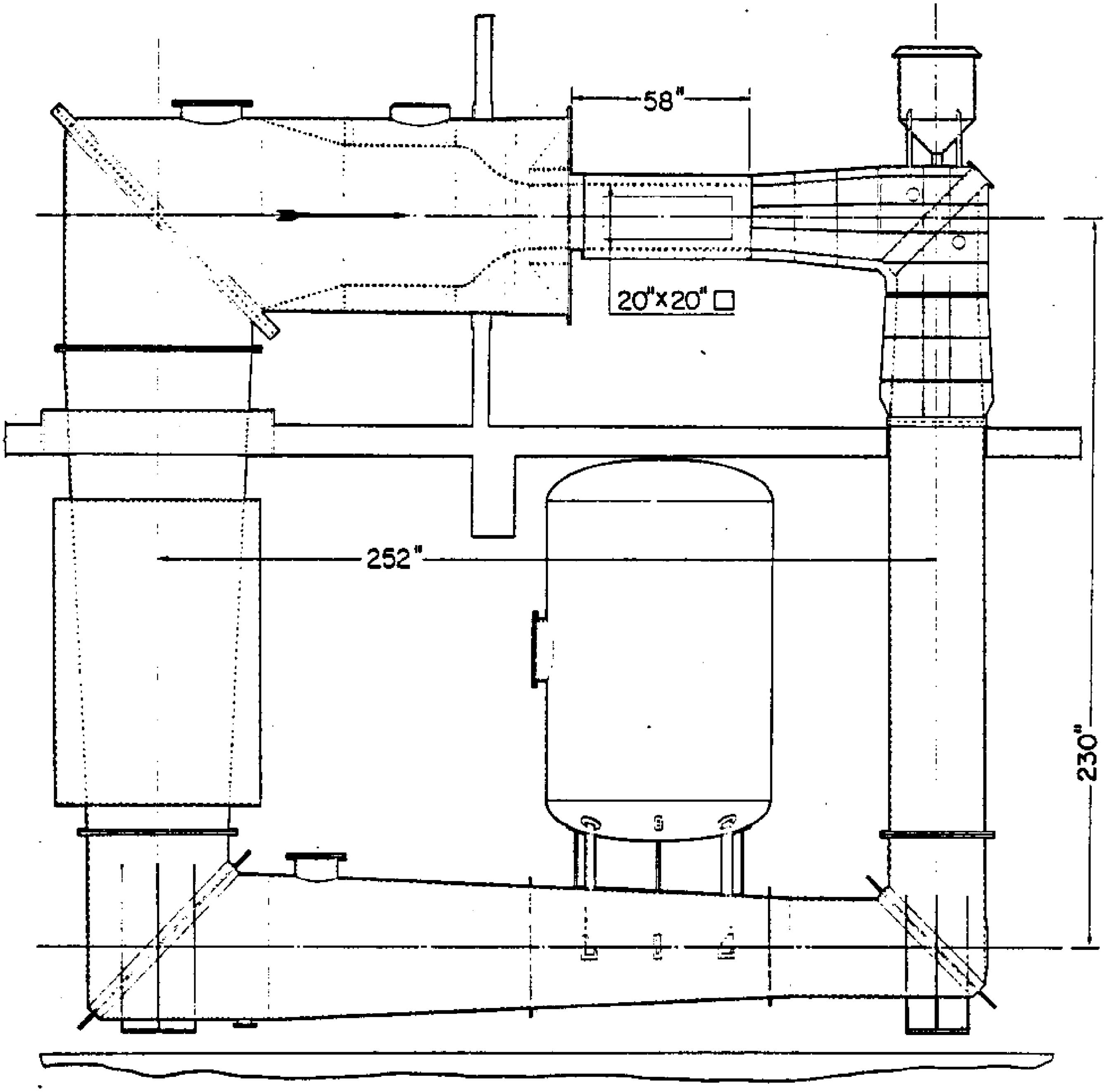


Figure 7. The variable pressure water tunnel located in the Marine Hydrodynamics Laboratory, Massachusetts Institute of Technology, Cambridge.

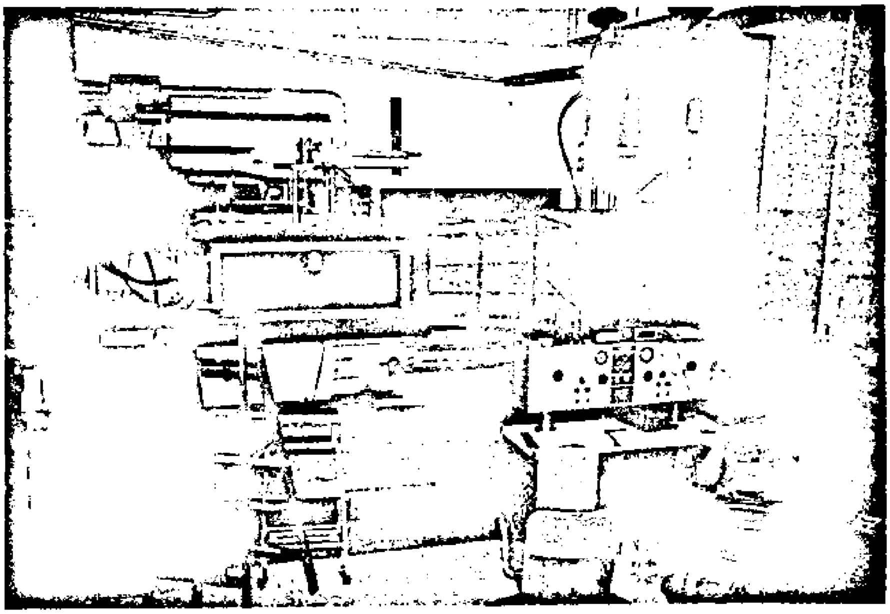


Figure 8. Water tunnel with model seen in test section. Control console and dynamometer digital readouts are in the lower right corner.

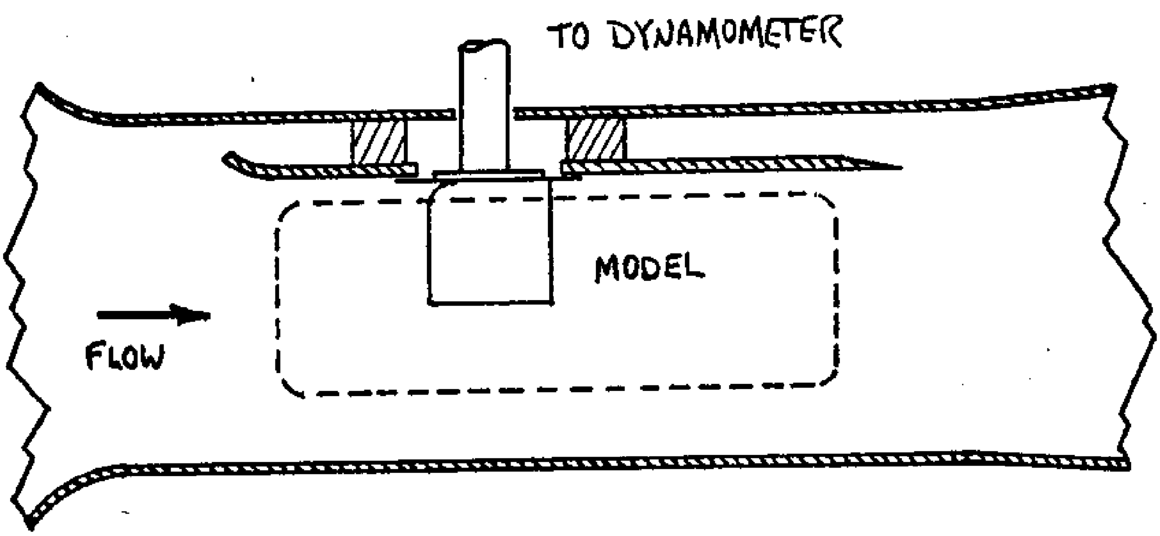


Figure 9. Test section with splitter plate

Models were mounted in the test section by removing one of the side viewing windows. With an initial setting of zero degrees angle of attack, the tunnel was filled and brought up to speed. The angle was then set to the lowest value desired and the velocity was allowed to stabilize. The manometer and load cell digital readings were recorded and the angle increased to the next setting. Increments of 2.5, 5.0, or 10.0 degrees were used, depending on the degree of detail desired. In general, the closer increments were used in the region of stall and/or probable operating area. The maximum range of data taken is from -20 to +50 degrees, however, some tests encompassed a lesser range when the extreme values seemed of little interest.

RESULTS OF SERIES TESTS

A computer program was developed to reduce the recorded data to coefficient form. The lift and drag coefficients respectively are defined by

$$C_L = L/(1/2\ \rho V^2 A) \qquad\qquad C_D = D/(1/2\ \rho V^2 A)$$

where L is the component of hydrodynamic force normal to the freestream; D is that component parallel to the freestream; ρ is the density of tunnel water; V is the freestream velocity and A is the model area. In these experiments, the rounded lower front corner of all models is neglected in calculating areas, i.e., for the rectangular models, the hydrodynamic area used is the chord length times the span, and for the nonrectangular models, the projected area is measured assuming the lower front corner is present.

Corrections have been made to the angle of attack and drag coefficient due to the presence of the tunnel walls using the methods of Glauert (11). A graphical presentation of this data is shown in the following figures in which C_L and C_D are plotted versus the angle of attack. Table I is a summary of this data.

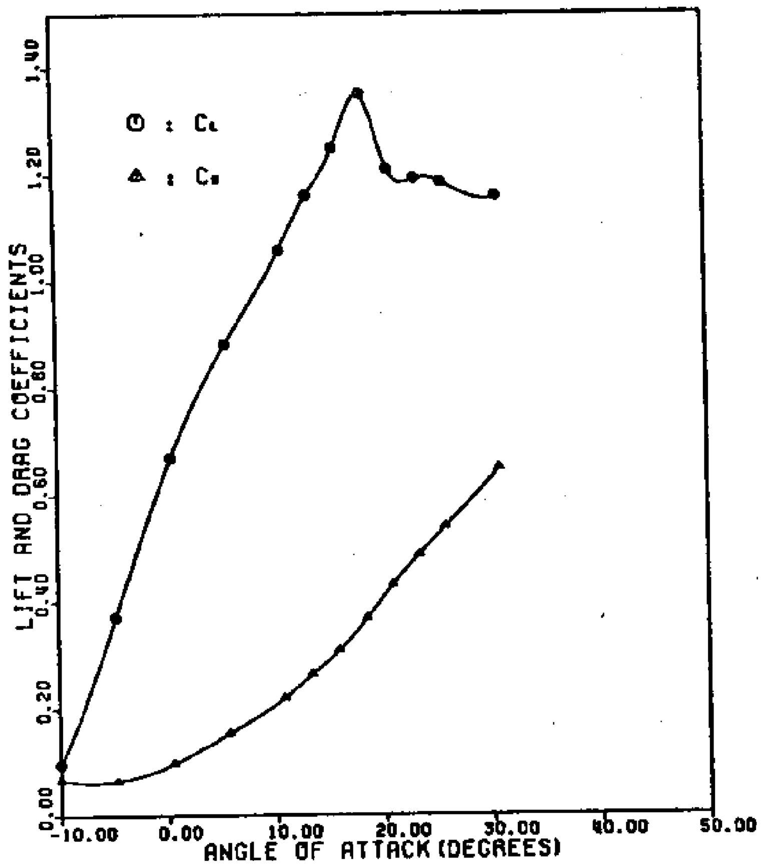


FIG. 10. RESULTS ORIGINAL MODEL

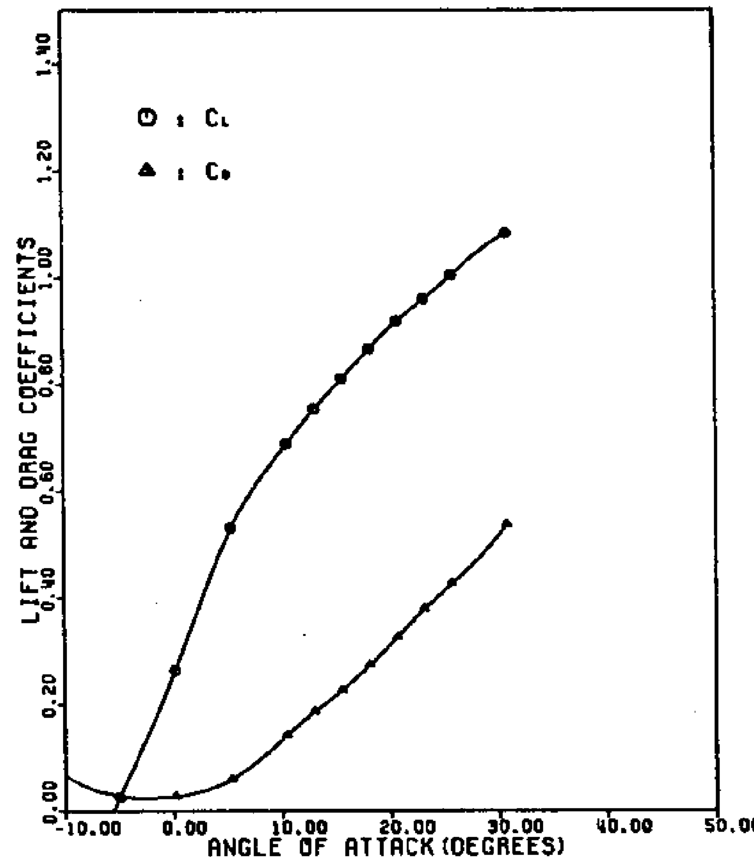


FIG.11. RESULTS MODEL C

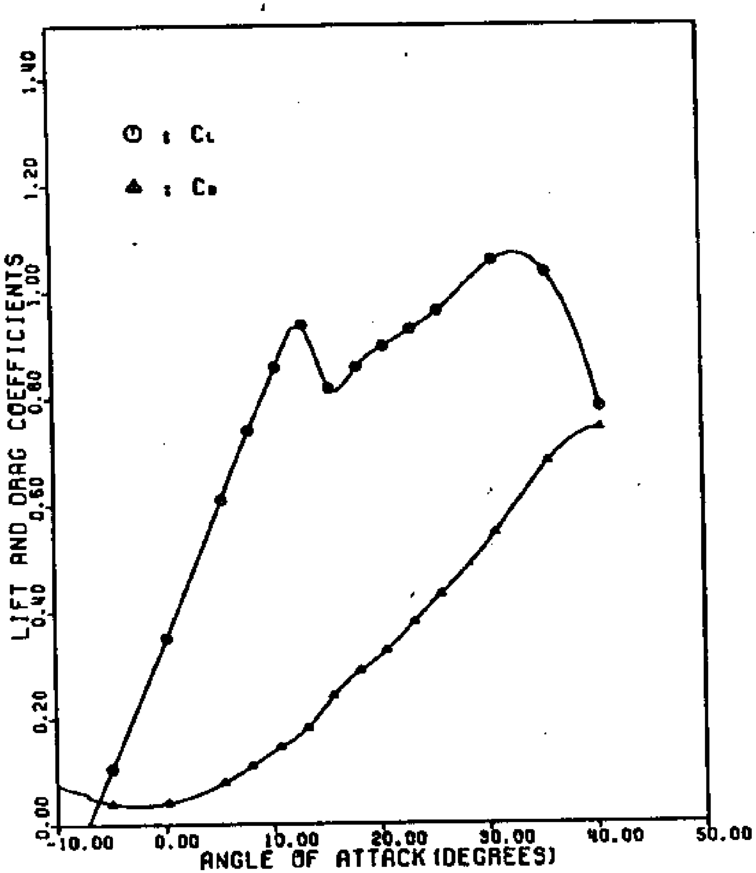


FIG. 12 RESULTS MODEL H

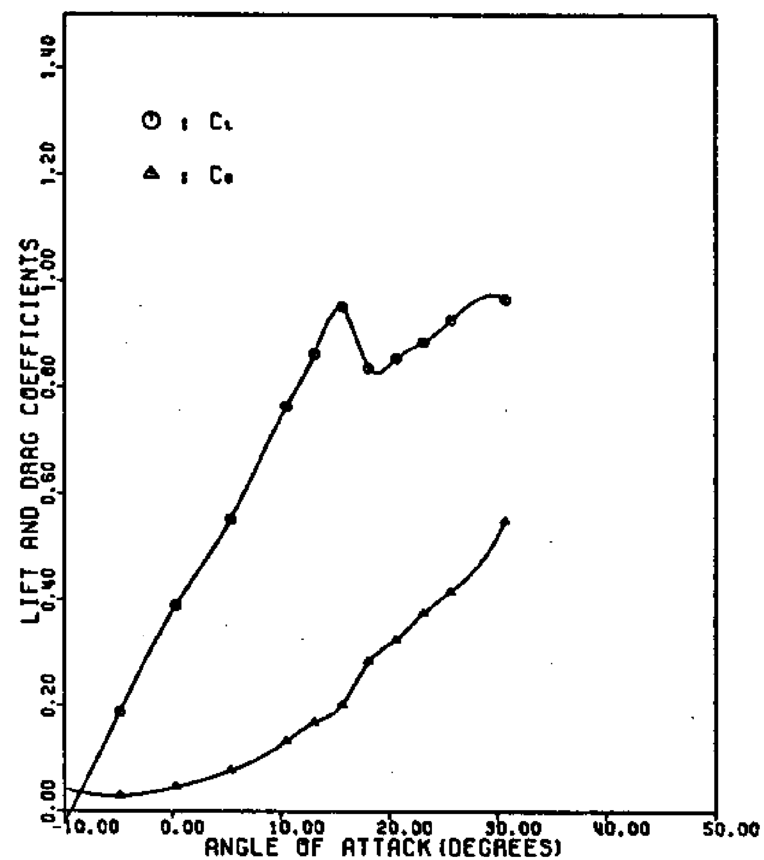


FIG. 13 RESULTS MODEL F

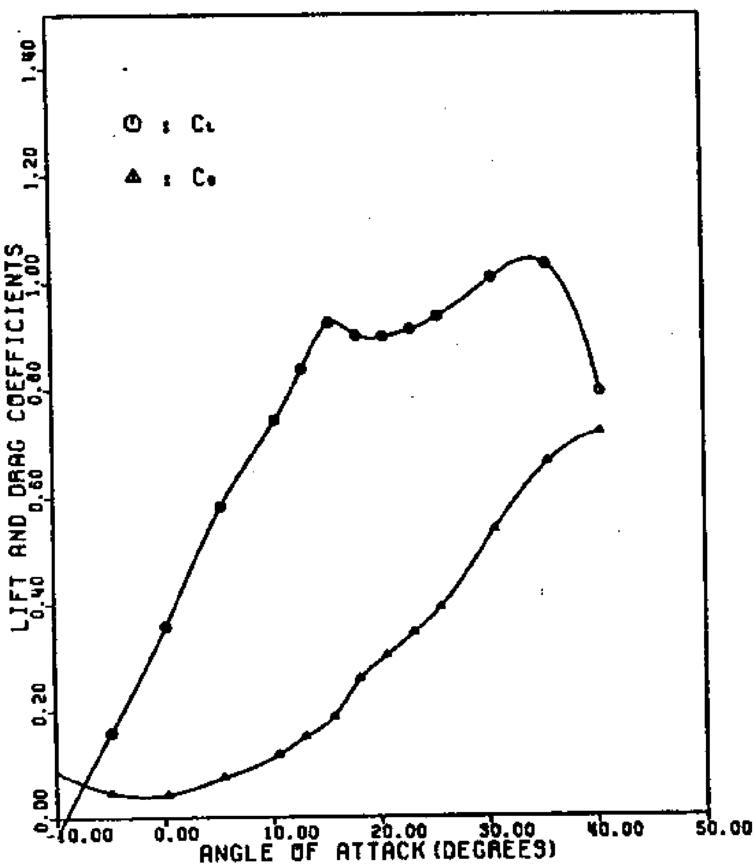


FIG. 14 RESULTS MODEL B

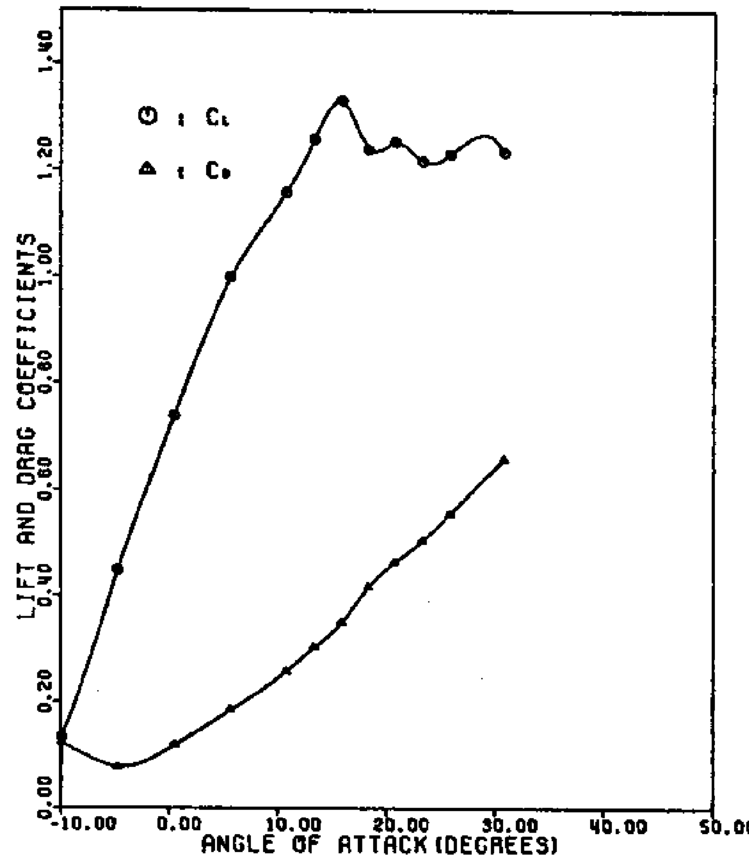


FIG. 15 RESULTS MODEL A

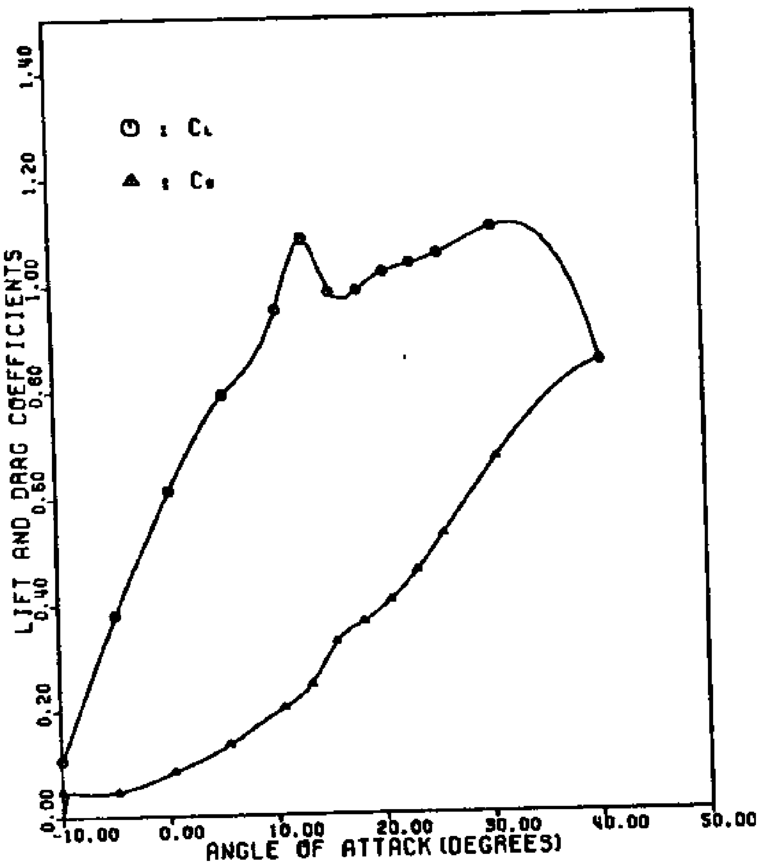


FIG. 16 RESULTS MODEL D

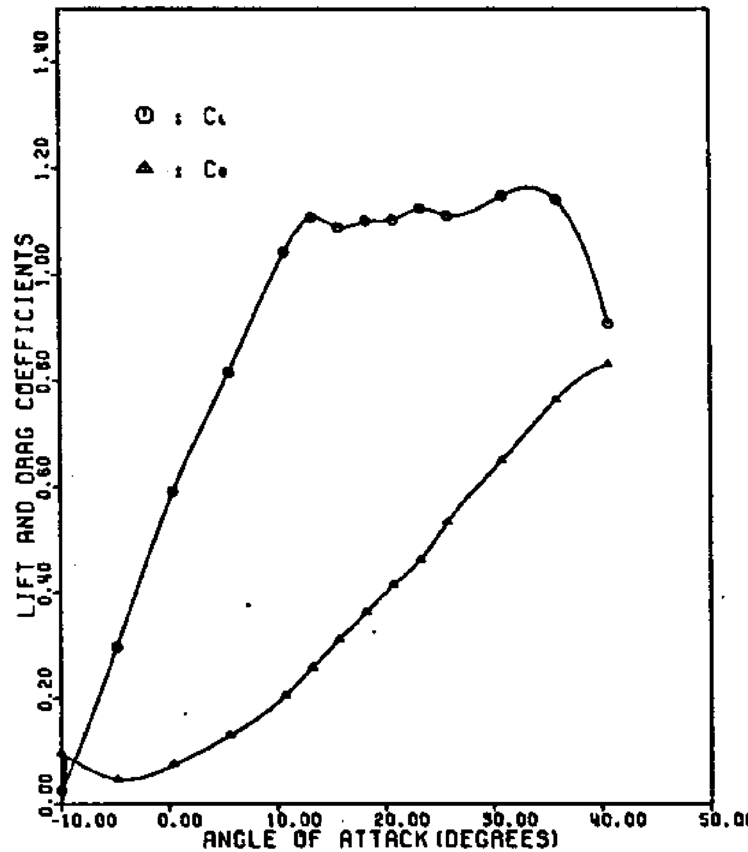


FIG. 17 RESULTS MODEL E

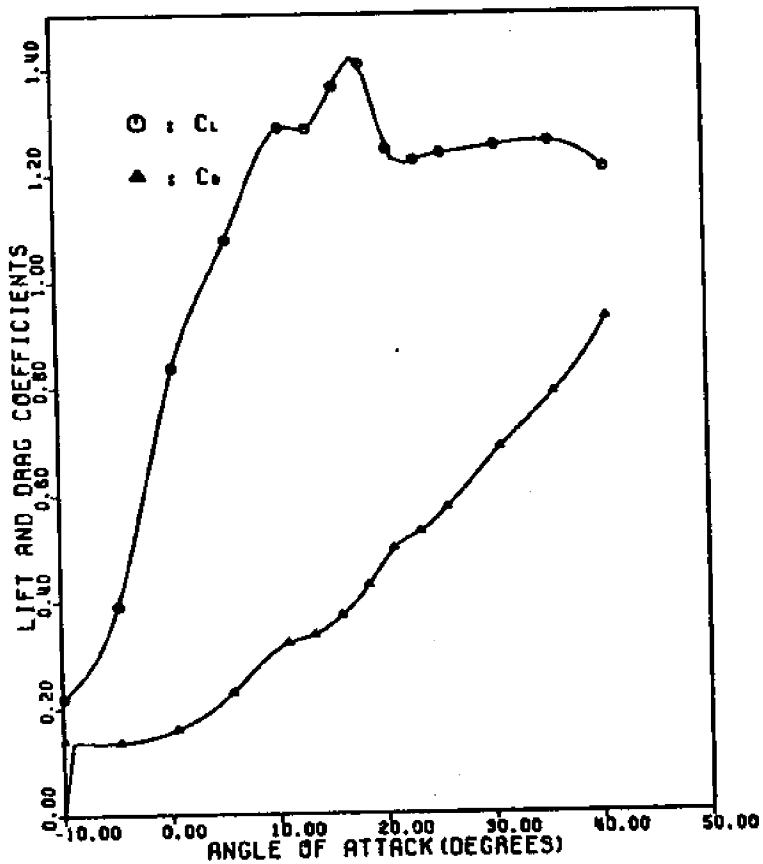


FIG. 18 RESULTS MODEL G

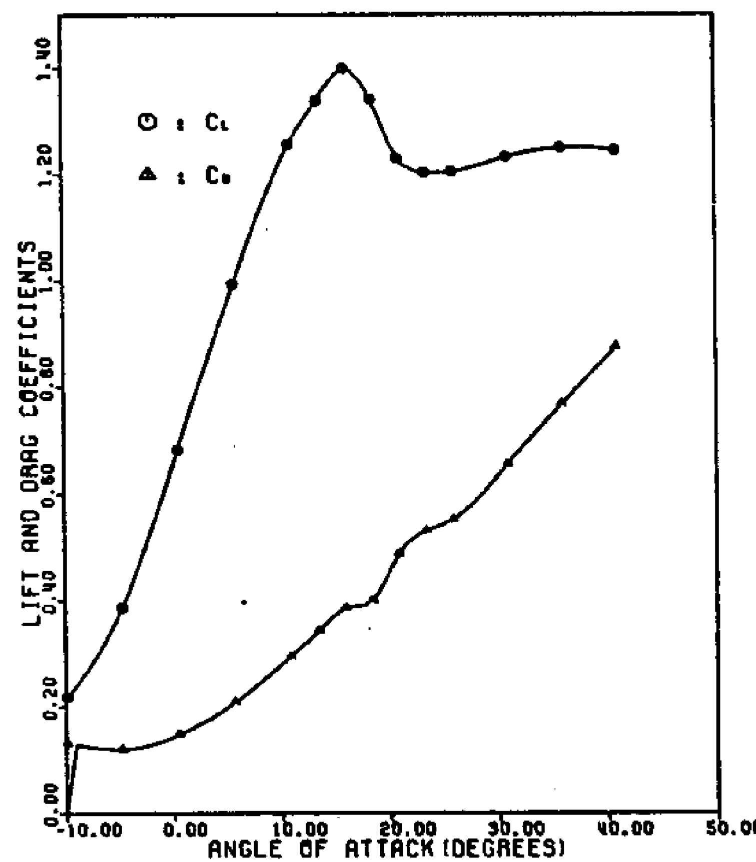


FIG. 19 RESULTS MODEL I

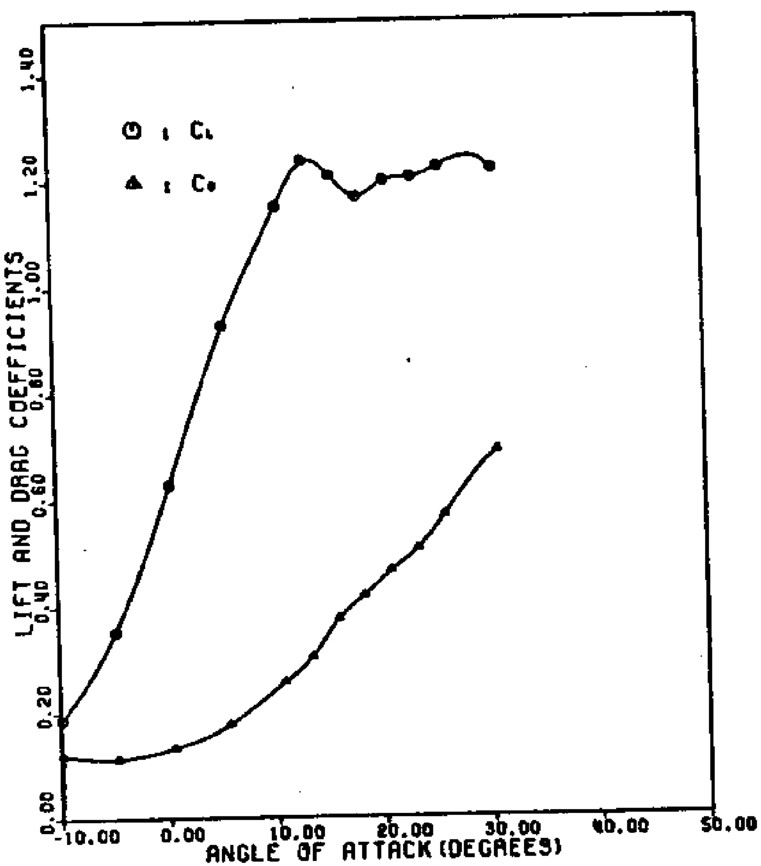


FIG. 20 RESULTS MODEL J

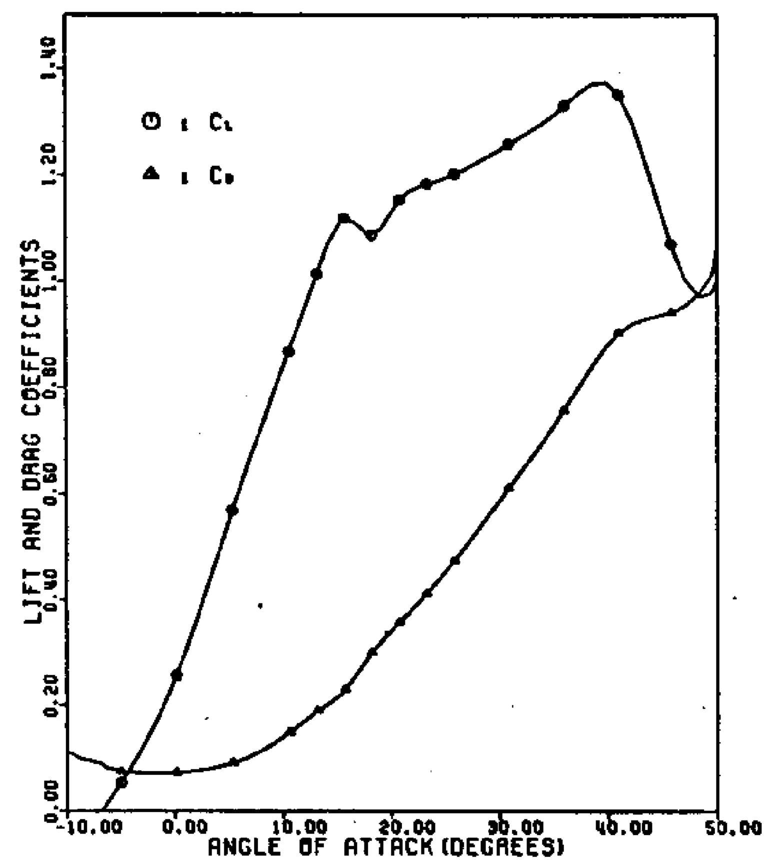


FIG. 21 RESULTS MODEL K

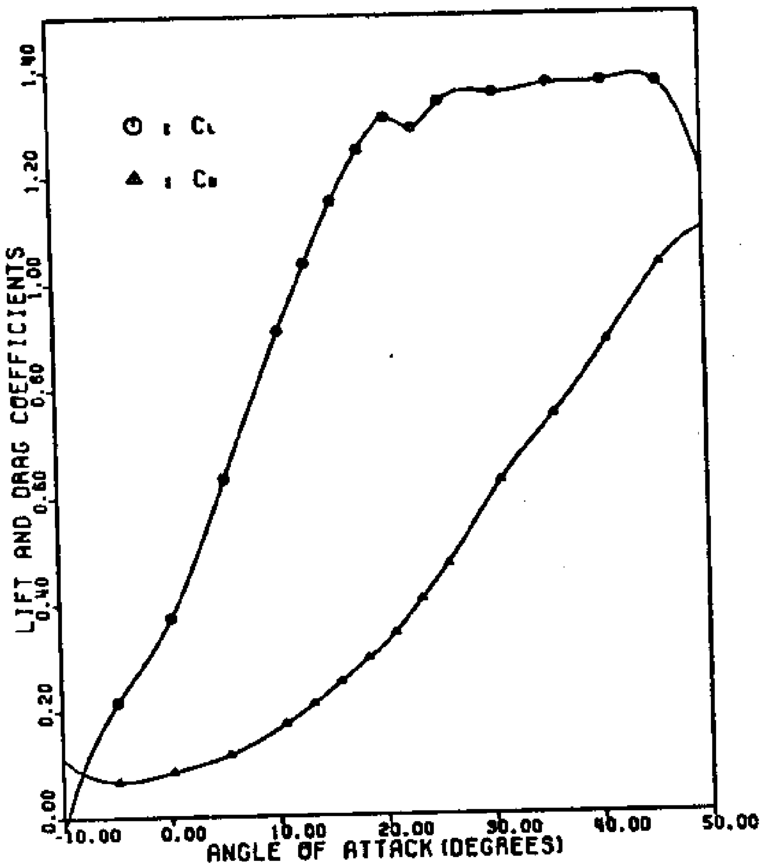


FIG.22 RESULTS MODEL L

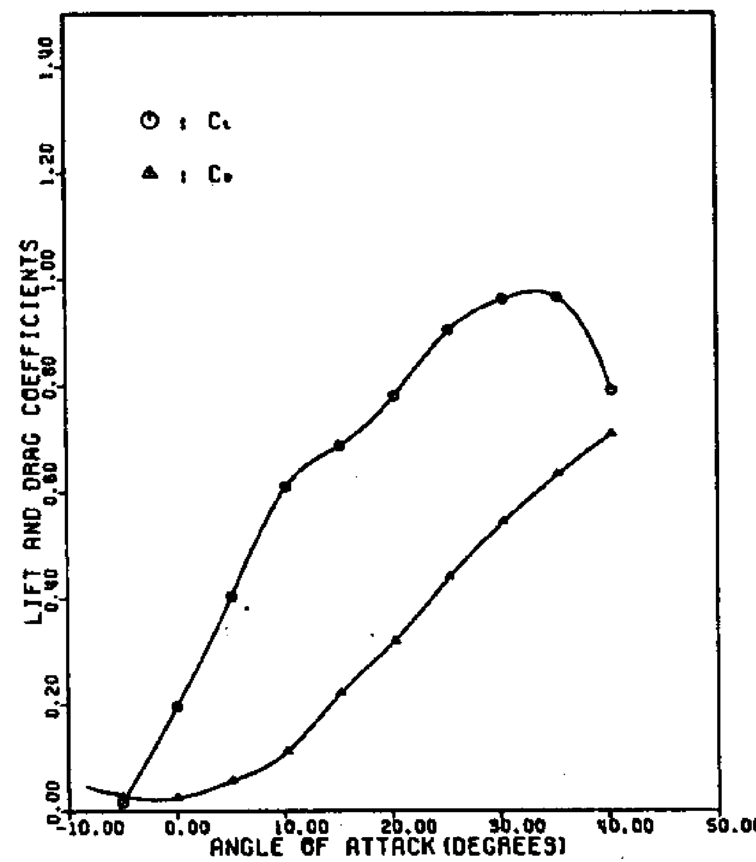


FIG. 23 RESULTS MODEL C MOD 1

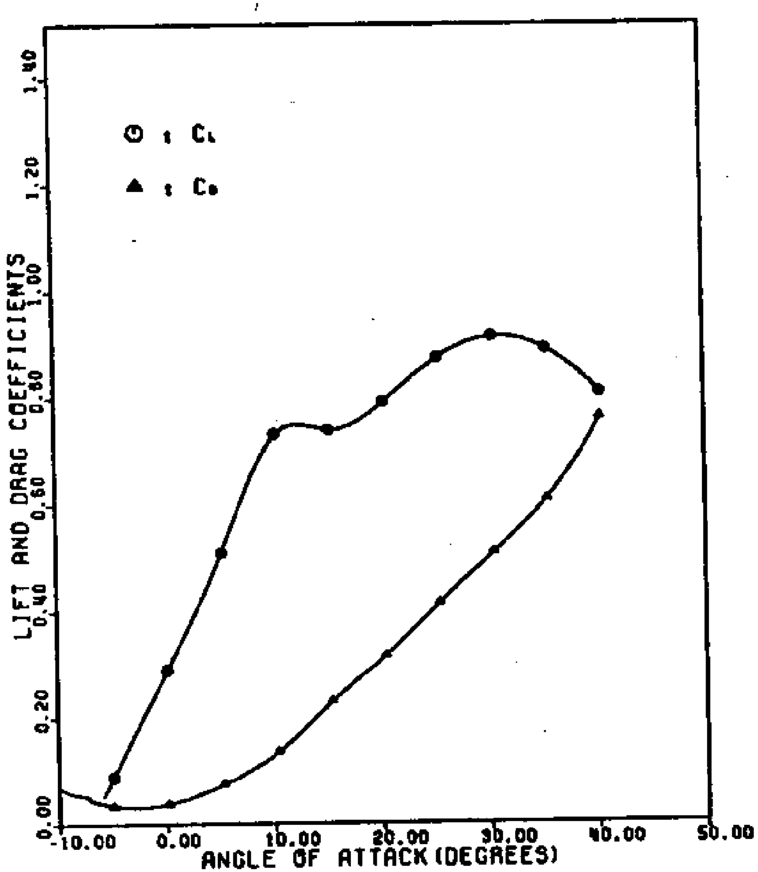


FIG. 24 RESULTS MODEL H MOD 1

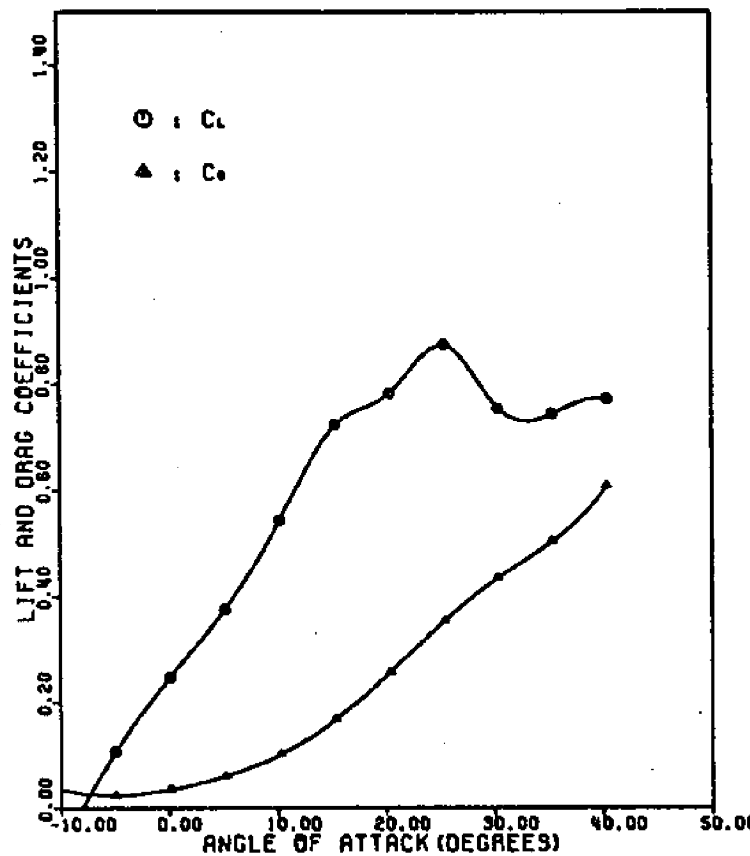


FIG. 25 RESULTS MODEL F MOD 1

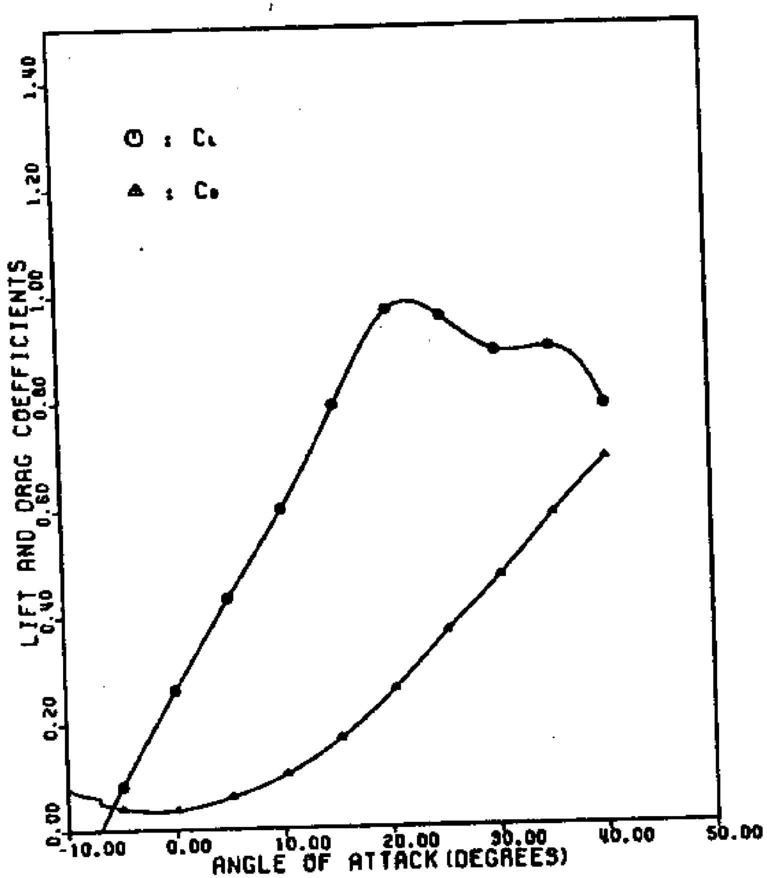


FIG. 26 RESULTS MODEL B MOD 1

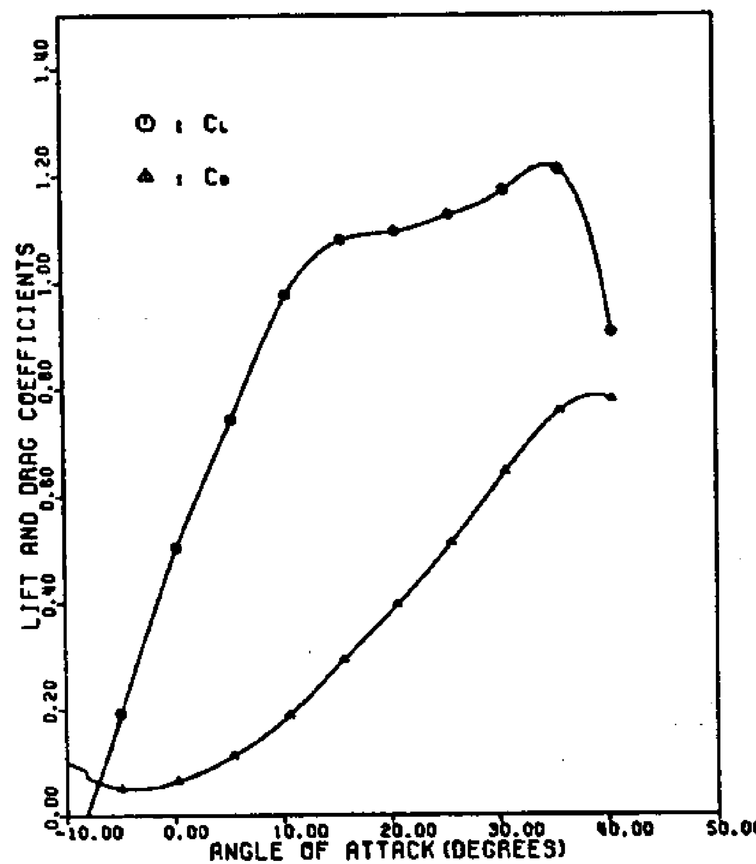


FIG. 27 RESULTS MODEL E MOD 1

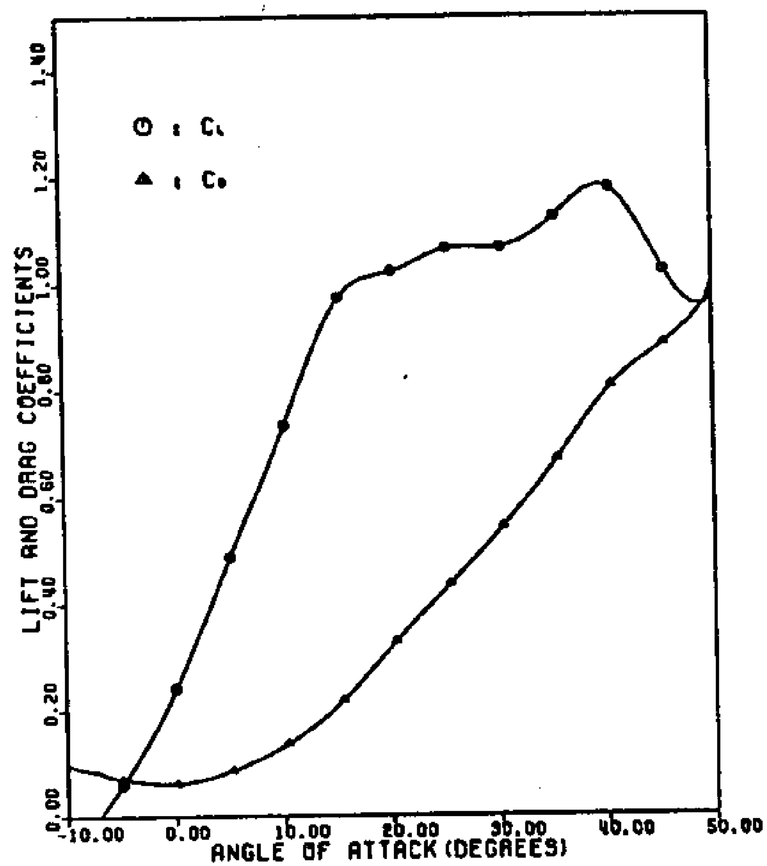


FIG. 30 RESULTS MODEL K MOD 1

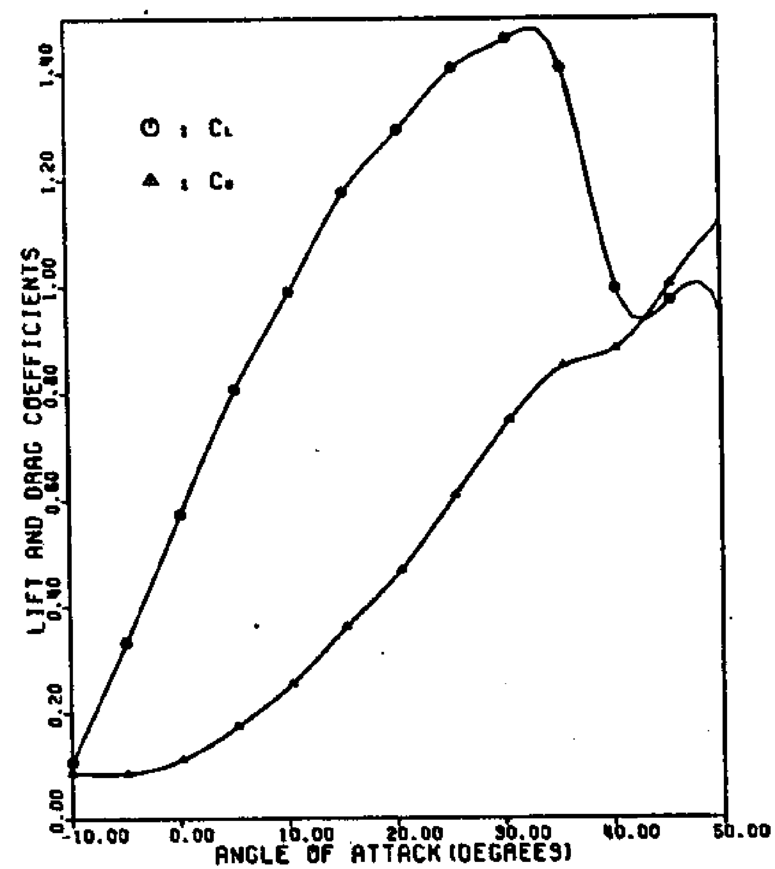


FIG.31 RESULTS MODEL A MOD 1

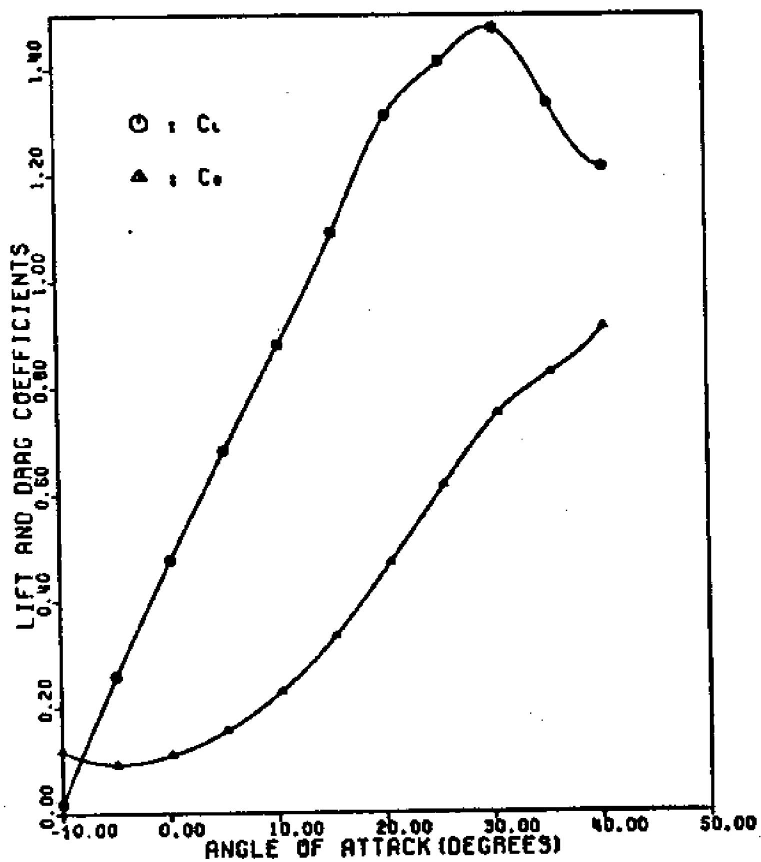


FIG. 28 RESULTS MODEL J MOD 1

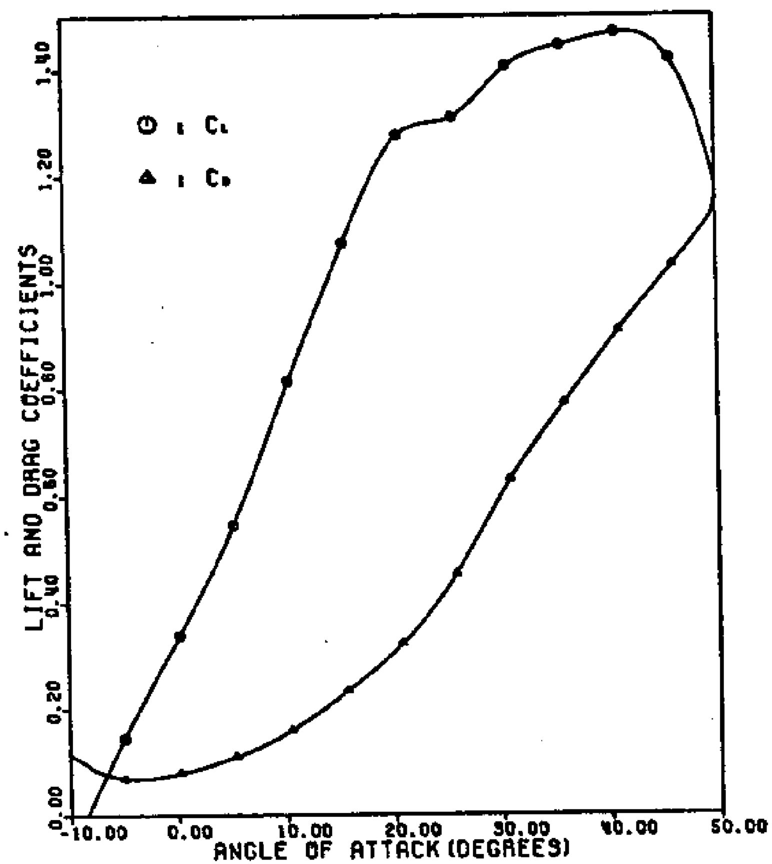


FIG. 29 RESULTS MODEL L MOD 1

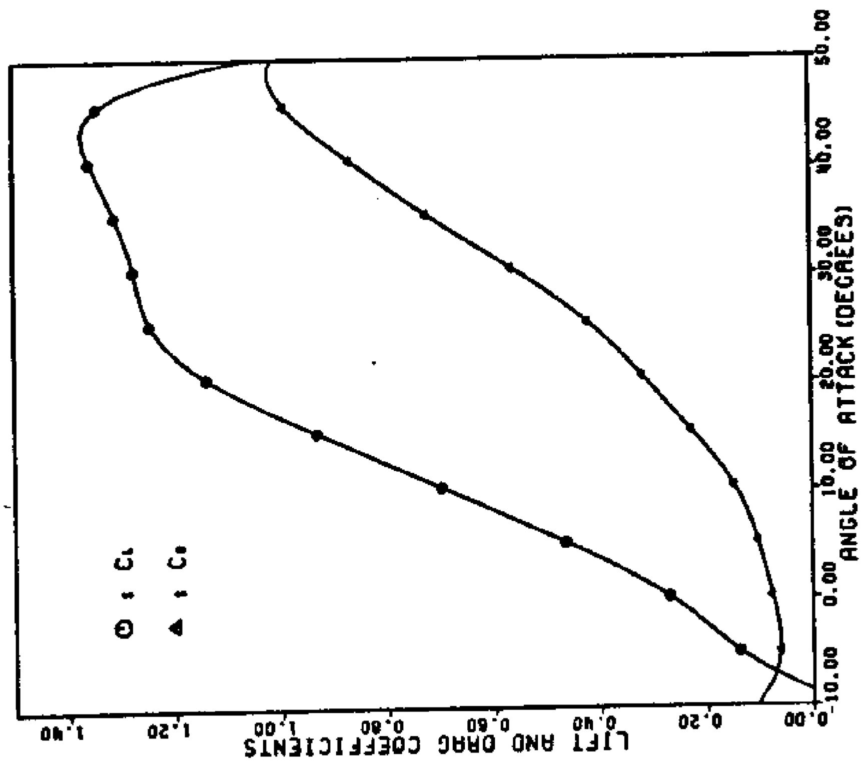


FIG. 32 RESULTS MODEL L MOD 2

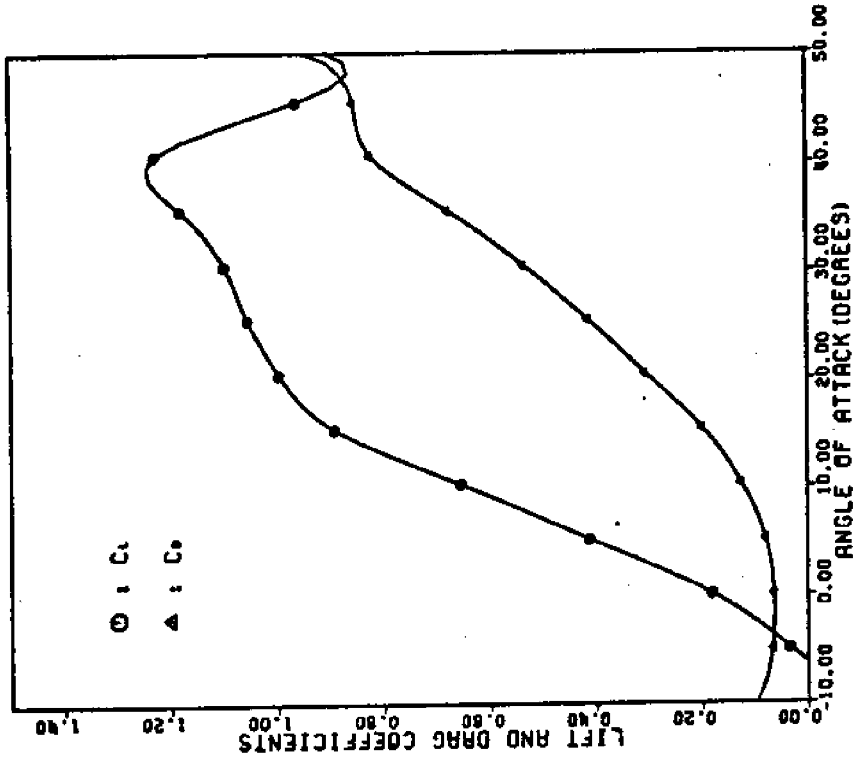


FIG. 33 RESULTS MODEL K MOD 2

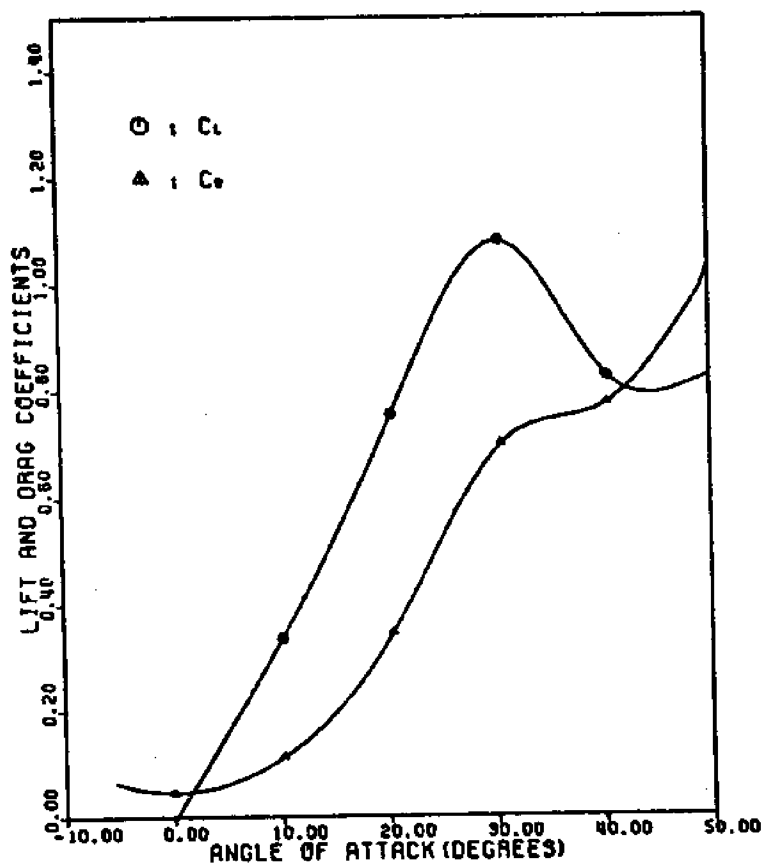
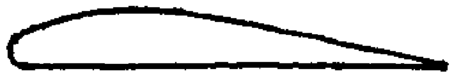
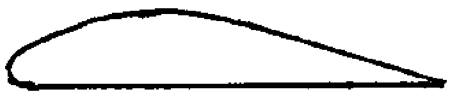
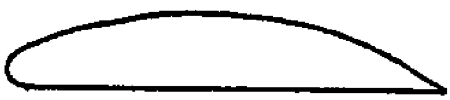
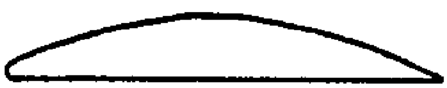
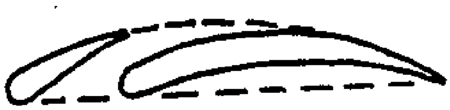


FIG. 34 RESULTS FLAT PLATE A=0.5

TABLE 1

Summary of Model Characteristics

Model	Profile	Aspect Ratio	Thickness (percent)	Camber (percent)	C_L max
C		1.00	14	6.3	1.08
C mod 1		.67			.97
H		1.00	18	6.2	1.07
H mod 1		.75			.91
F		1.00	16	5.3	.97
F mod 1		.83			.87
B		1.00	13	3.3	1.04
B mod 1		.70			.98
K		1.00			1.37
K mod 1		.75			1.18
K mod 2		.71			1.23
L		1.00			1.38
L mod 1		.96			1.47
L mod 2		.71			1.37
Flat Plate		.5	4.7	0	1.08

DISCUSSION OF SERIES TESTS

To better compare the various models, figures 35 through 50 are presented, with the prototype model often included as a standard. From these figures, the effect of parameter changes can be seen, however, caution must be excercised in drawing any conclusions regarding the effects on foils of other geometry.

Effect of thickness

Figure 35 compares three models of differing thickness ratios. The thinner models (Sea Grant and model A) perform much the same while the thicker foil, model D, shows lower values of C_L and can be considered inferior, however, this could be due to the reduced camber of the design. Models C and H, shown in figure 37 isolate better the effects of variations in thickness. Here the thicker model generates more lift at lower angles of attack, but after an abrupt stall, the C_L plots nearly coincide.

Thickness, therefore, can be considered of minor importance to a trawl board's hydrodynamic performance. It can be used to provide structural rigidity without detriment, at least within the range tested.

Effect of camber

Most of the variation shown in figure 35 could be attributed to changes in camber, especially the lower C_L values of model D. The importance of high camber in producing high lift coefficients is well documented in aerodynamics (7,12,13) and this applies as well to trawl doors. Some increase in C_D values is to be expected and both coefficients must be considered in evaluation.

Figure 36 shows the beneficial effect of camber among the three models compared. The increase in lift coefficient of model G both before and after stall is significant. However, the accompanying increase in drag coefficient yields L/D values lower than the original door model.

In trawl board design, high camber and the accompanying higher lift coefficients could result in a smaller, less expensive and easier handling door, but acceptable L/D values must be attained.

Effect of nose radius

Models F and B, shown in figure 37, were intended in part to determine the importance of this parameter. The relatively sharper leading edge of model B had little effect on the lift or drag curves. The anticipated effect of delayed stall with the larger nose radius (14) was not found. It should be noted however, that, due to geometric considerations, the changes in nose radius were not accomplished without altering the model thickness and camber. Therefore, the comparison of models B and F is not conclusive.

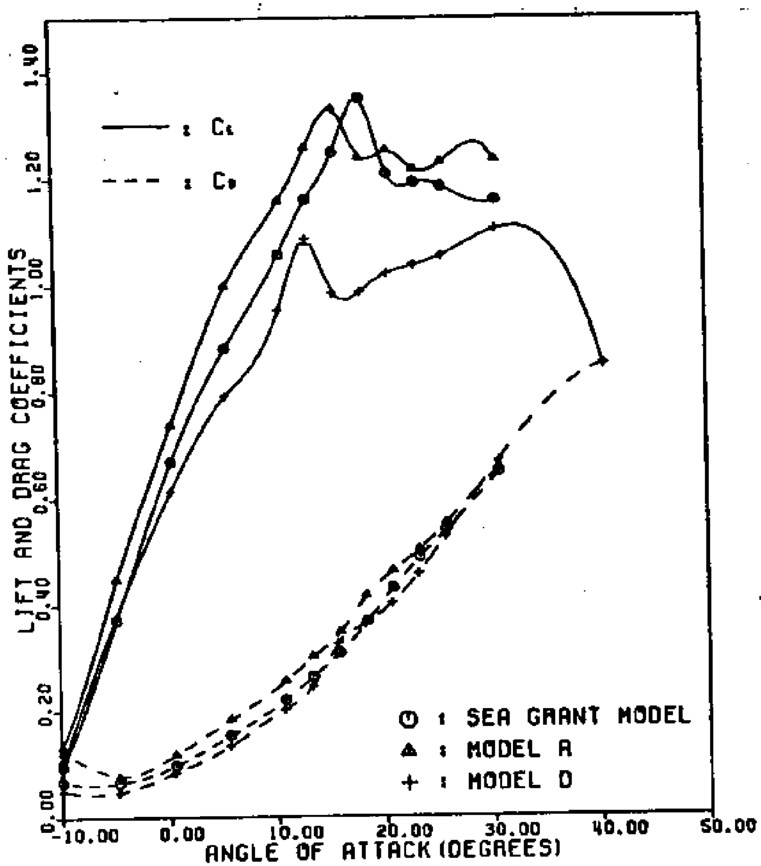


FIG. 35 COMPARISON OF ORIGINAL, THINNER AND THICKER MODELS

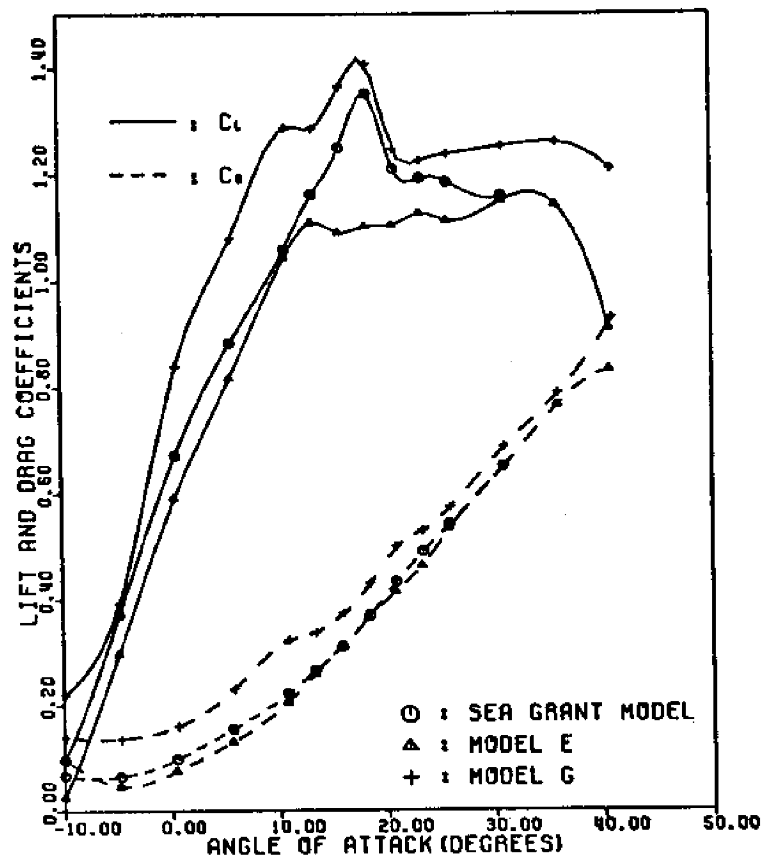


FIG. 36 COMPARISON OF ORIGINAL, LOW CAMBER AND HIGH CAMBER MODELS

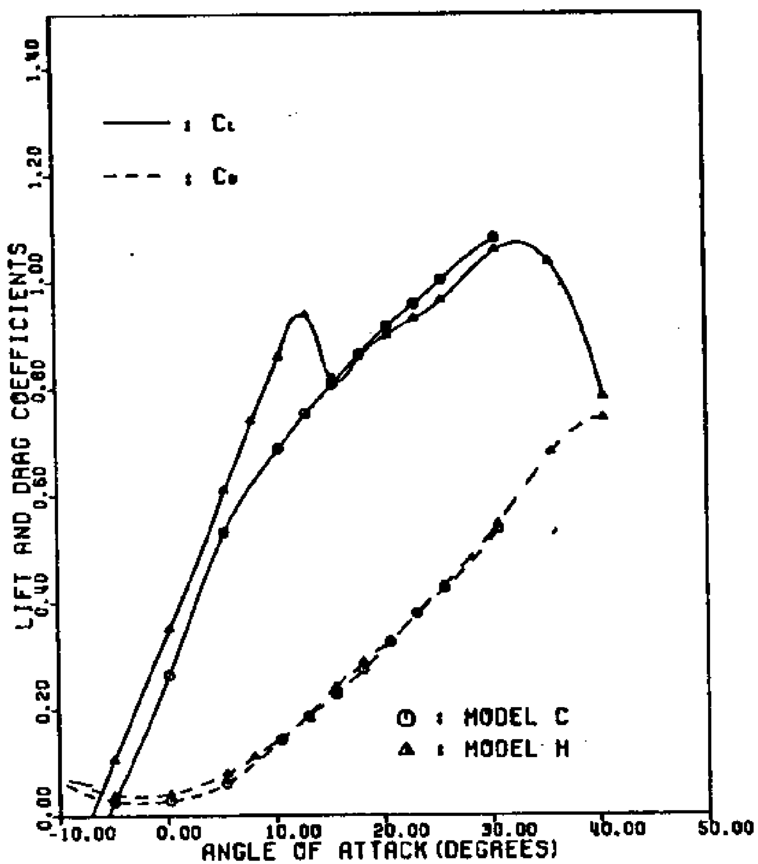


FIG. 37 COMPARISON OF MODEL C AND MODEL H

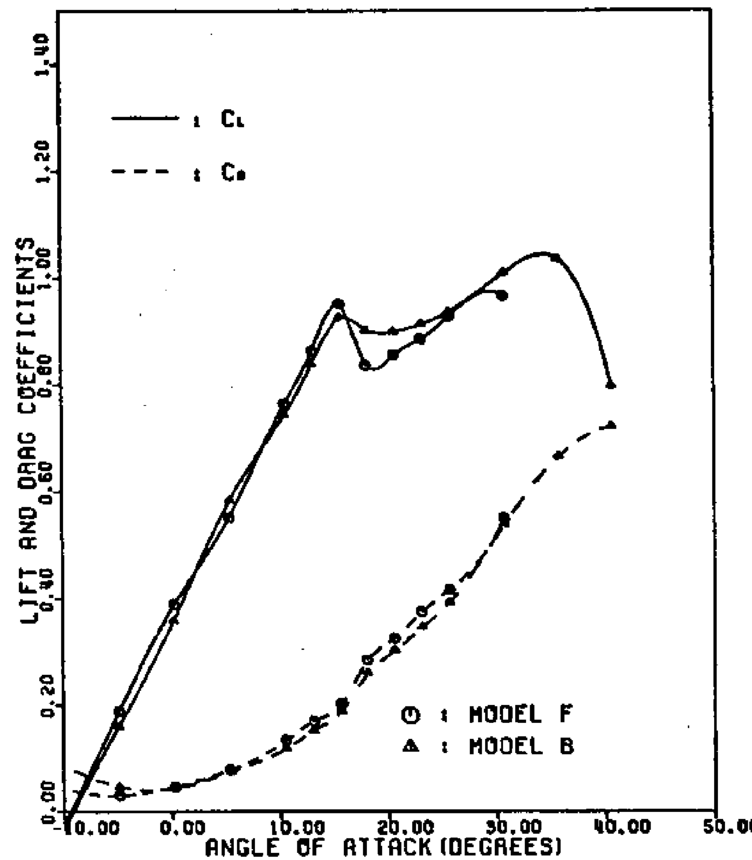


FIG. 38 COMPARISON OF MODEL F AND MODEL B

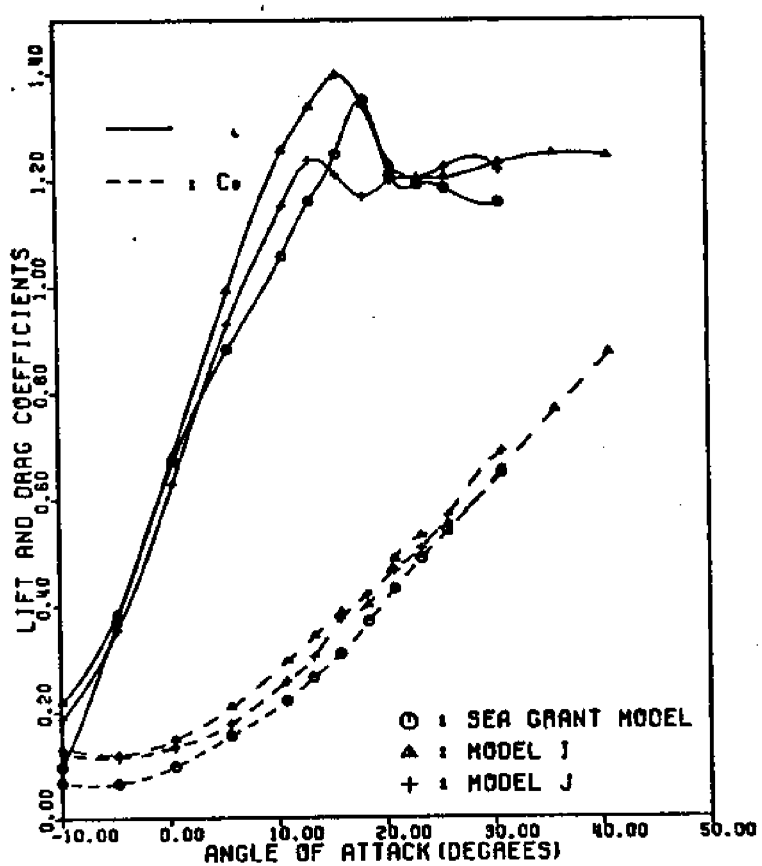


FIG. 39 COMPARISON OF ORIGINAL AND OTHER SECTION SHAPES

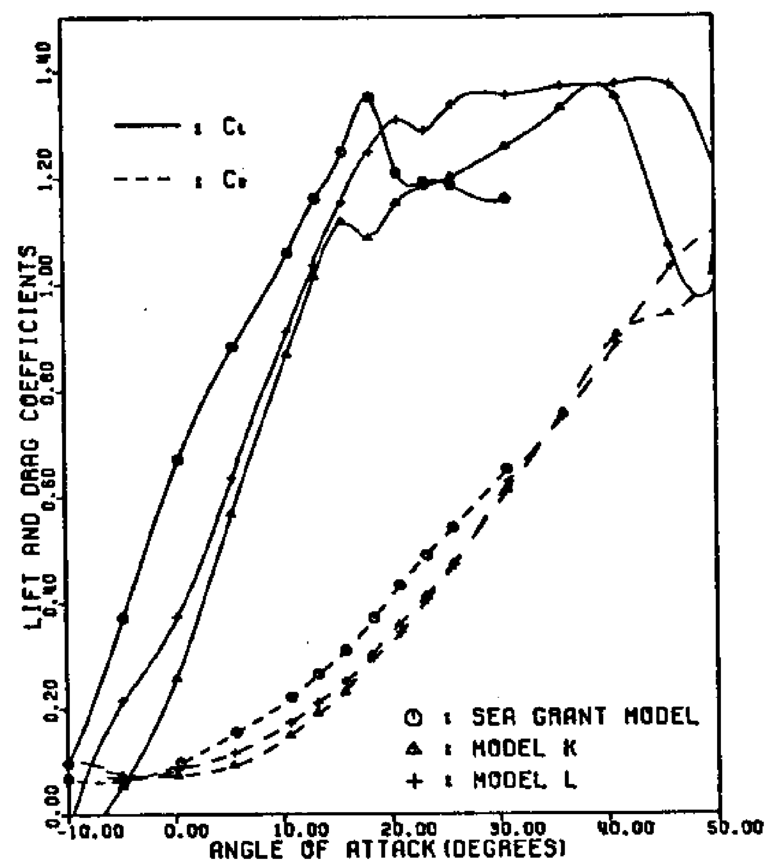


FIG 40 COMPARISON OF ORIGINAL AND SLOTTED MODELS

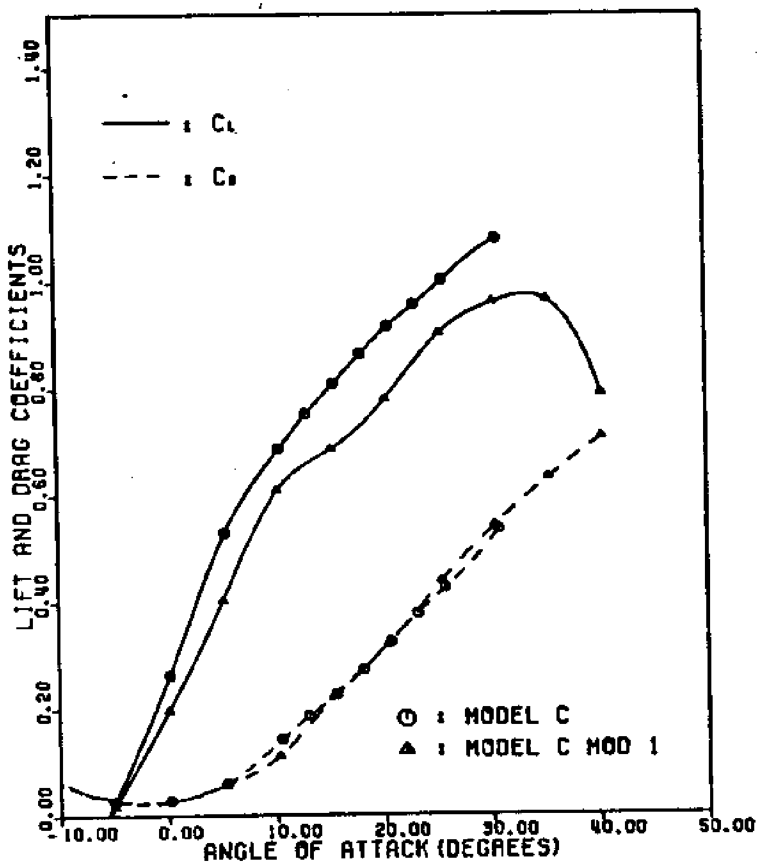


FIG. 41 COMPARISON OF MODEL C AND MODEL C MOD 1

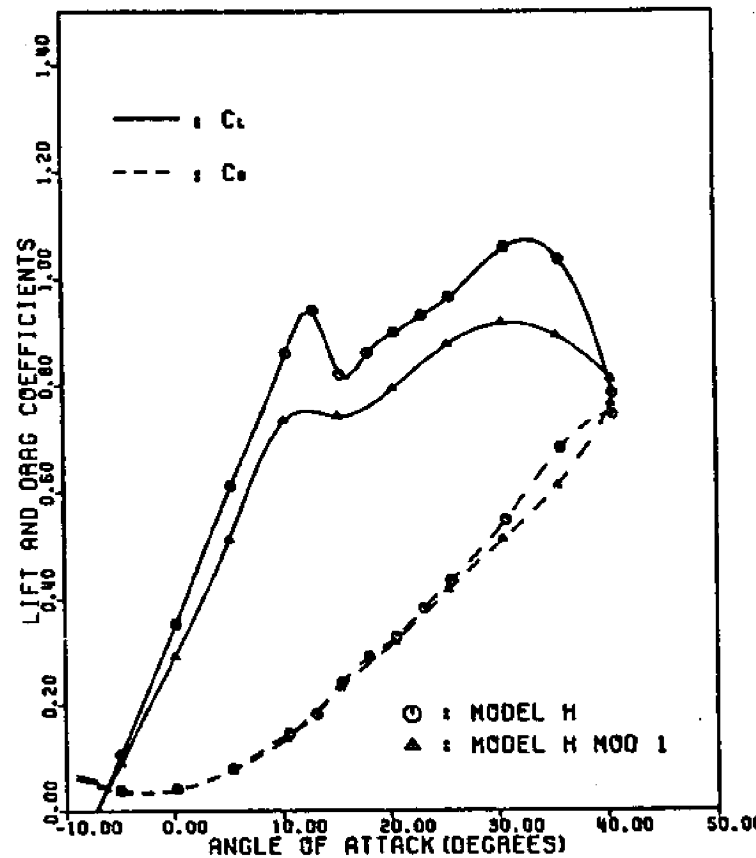


FIG. 42 COMPARISON OF MODEL H AND MODEL H MOD 1

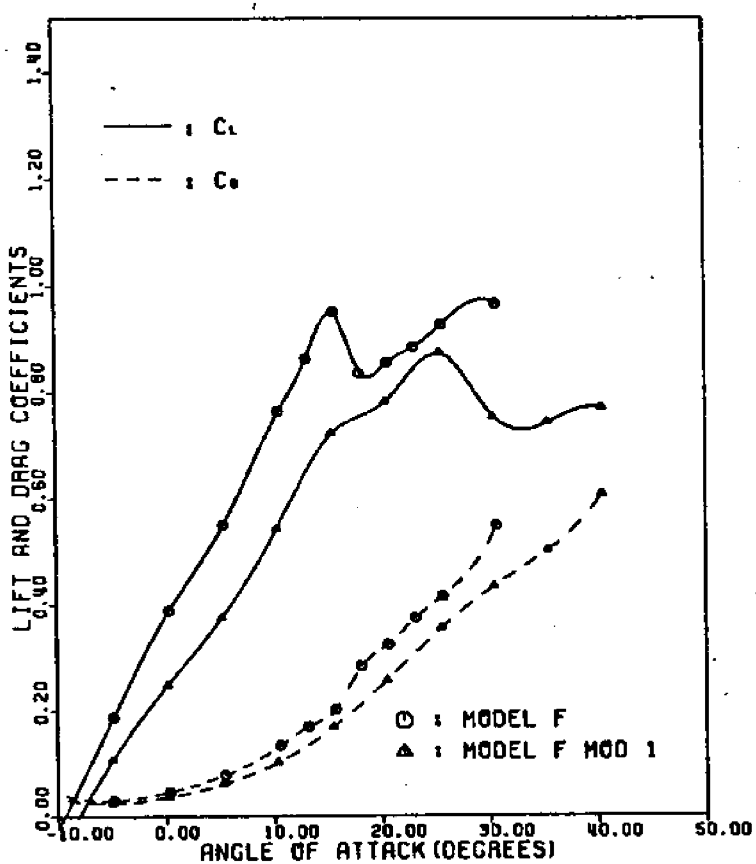


FIG 43 COMPARISON OF MODEL F AND MODEL F MOD 1

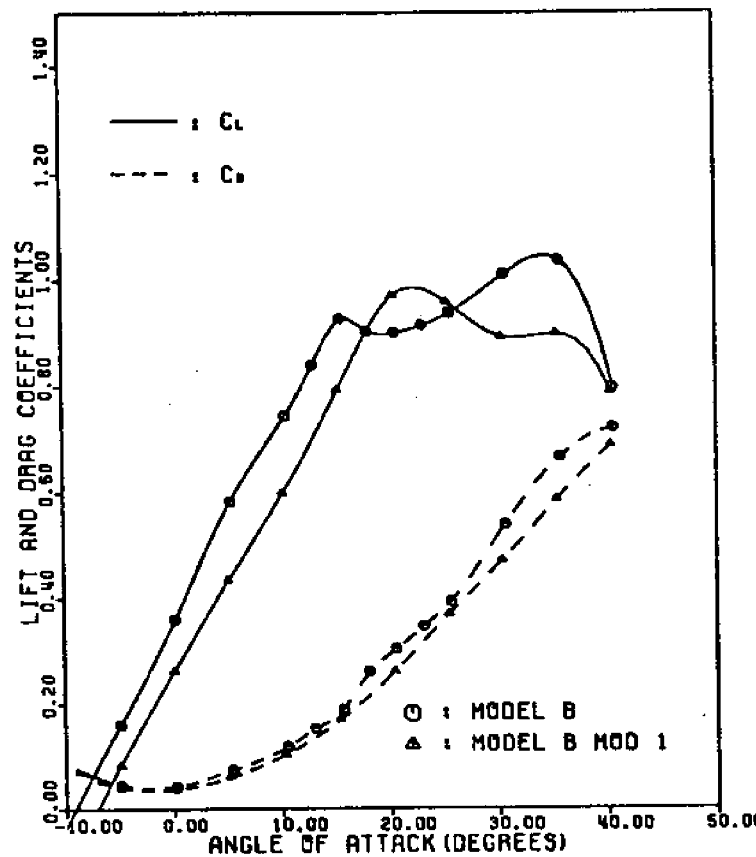


FIG. 44 COMPARISON OF MODEL B AND MODEL B MOD 1

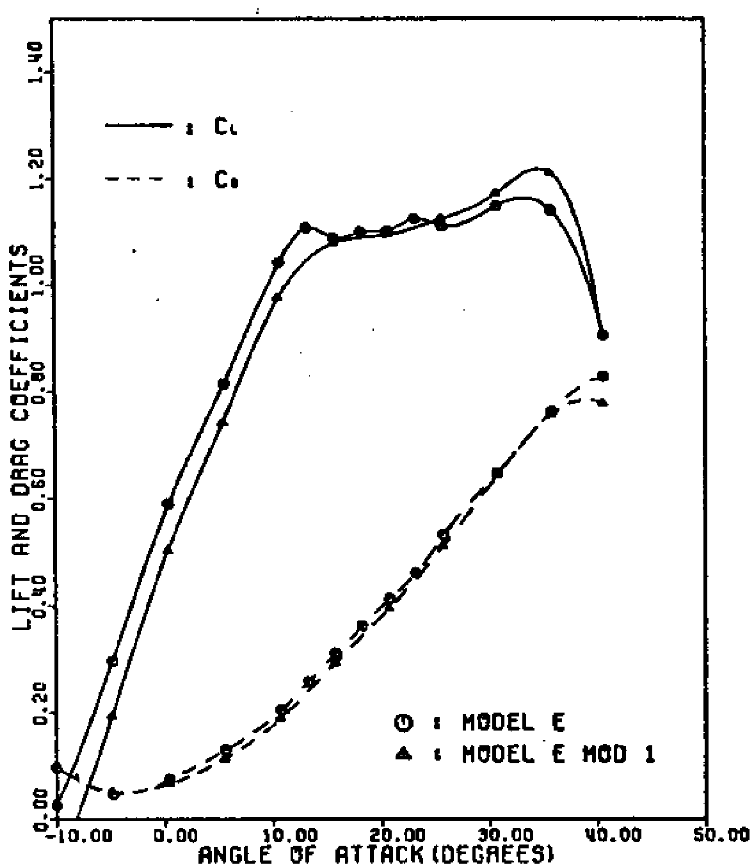


FIG.45. COMPARISON OF MODEL E AND MODEL E MOD 1

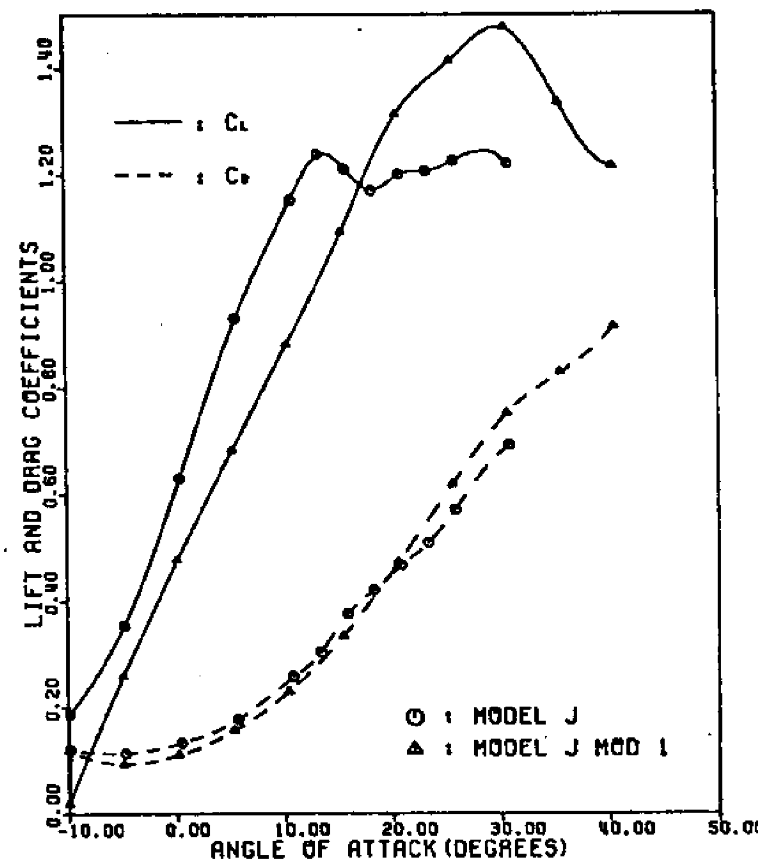


FIG 46. COMPARISON OF MODEL J AND MODEL J MOD 1

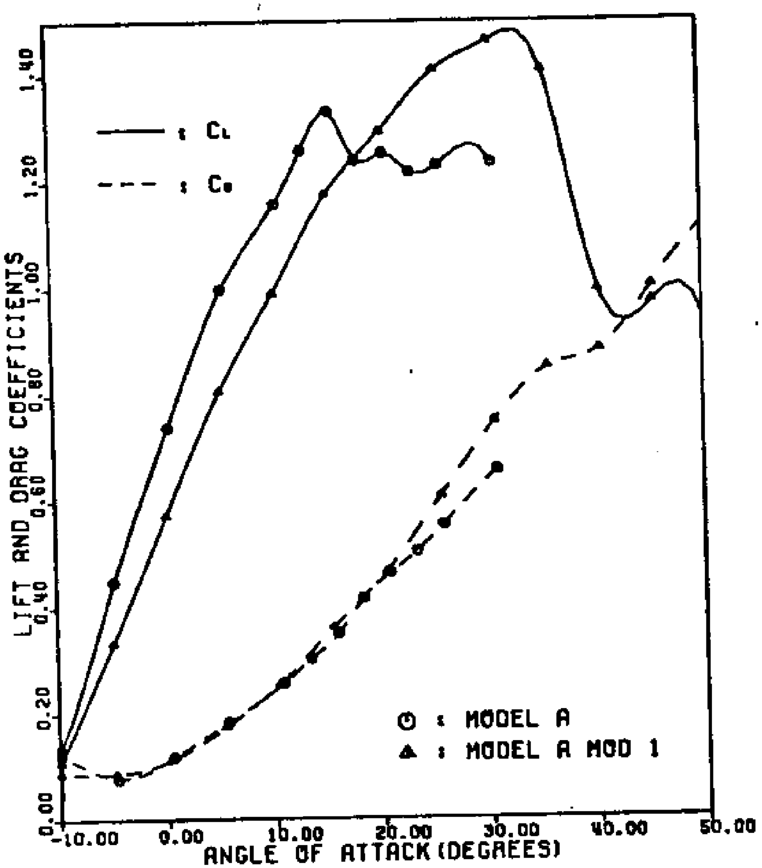


FIG. 47. COMPARISON OF MODEL A AND MODEL A MOD 1

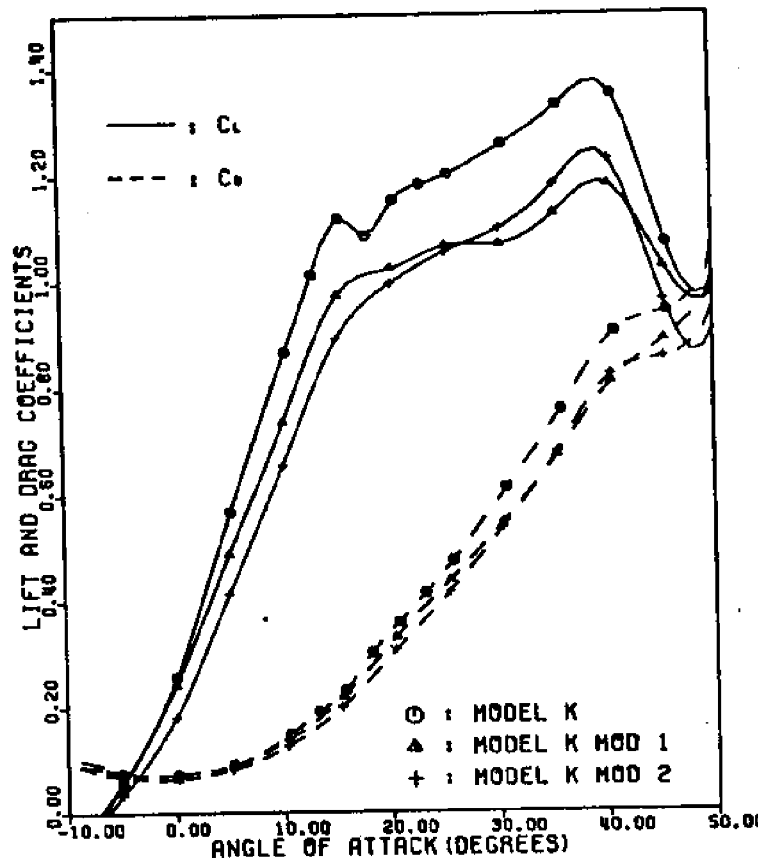


FIG. 48 COMPARISON OF MODELS K, K MOD 1 AND K MOD 2

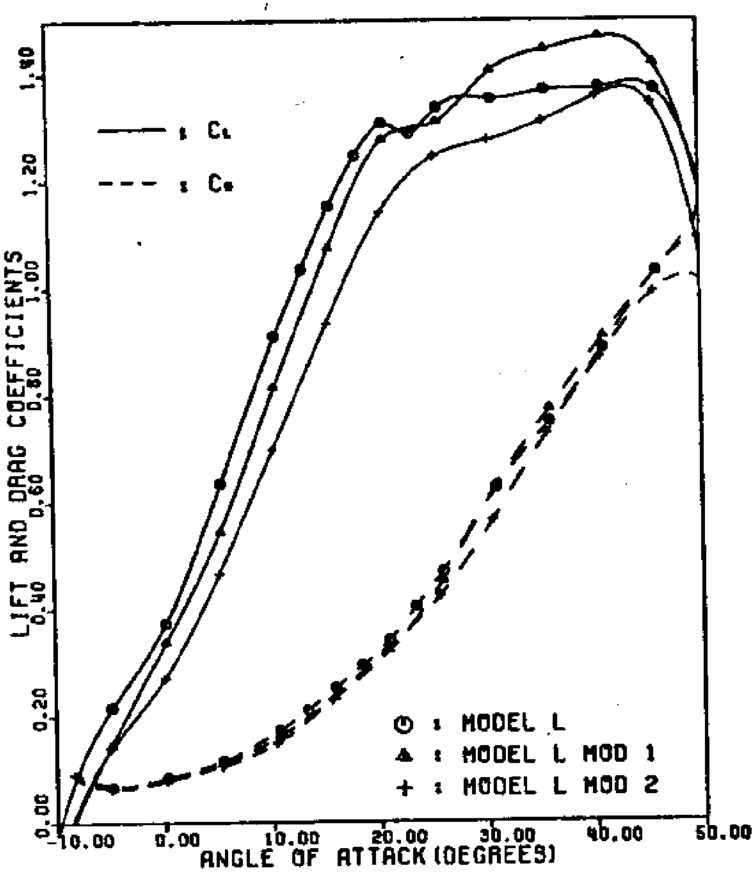


FIG.49 COMPARISON OF MODELS L, L MOD 1 AND L MOD 2

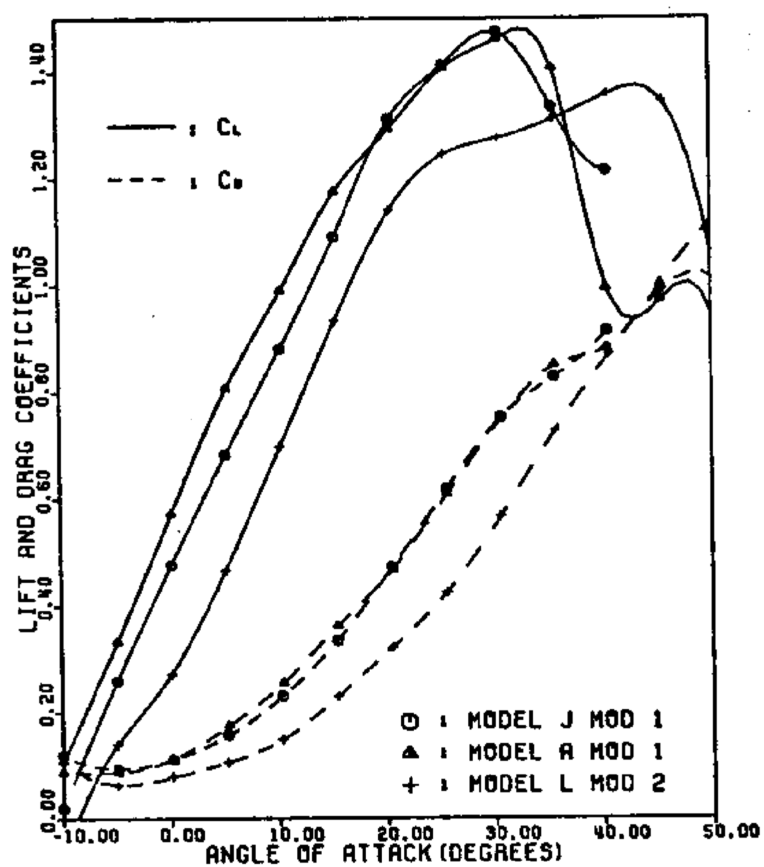


FIG.50 COMPARISON OF THREE LOW ASPECT RATIO MODELS

Effect of sectional shape

The different sectional shapes shown in figure 39 represent no real improvement in performance over the original model. Unlike the models in which thickness and camber was varied, these models showed remarkable similarity, especially for angles of attack greater than 20 degrees. Unlike foil sections of higher aspect ratio, where subtle variations in sectional shape have a great effect on performance, the low aspect ratio models of this study require gross changes in sectional parameters to significantly affect performance. This tends to support the use of constant radius surfaces rather than the more conventional aerodynamic shapes. Low aspect ratio and high angle of attack foils appear quite forgiving in this respect.

Effect of aspect ratio

Since these tests were conducted with the model in contact with the splitter plate to simulate hydrodynamic blockage of the seabed, the effective aspect ratio is twice that of the actual model. These results, therefore, can be useful in the design of a mid-water trawl board by properly taking this into account.

All modifications to the original models represented changes in aspect ratio. As expected, the general trend seen in figures 41 through 47 indicates lower lift coefficients for models of lower aspect ratio. Other general effects are delayed stall, less loss of lift after stall and lower drag coefficients. Notable exceptions to this are models A mod 1 and J mod 1, where increases in C_L of 11% and 18.5% are seen respectively. This phenomenon was described by Winter (5) and Zimmerman (6). Both found the general trend of lower lift coefficients with shorter span, however, a local increase in C_L max. was found at aspect ratios around unity. This may account for the characteristics of models A mod 1 and J mod 1 since, due to the mirror image effect of the splitter plate, these lower aspect ratio modifications are approaching this range.

Optimum aspect ratio can vary depending on the sectional shape. Operational considerations favor lower aspect ratio while efficiency from both size and drag standpoints favors higher aspect ratio. Models such as A mod 1 and J mod 1 provide an interesting compromise.

Effect of planform

Model E mod 1 was intended to test the effect of a more rounded planform on hydrodynamic characteristics. Little difference is seen in figure 45 between the two models. Compared with other parameters, planform has been shown to be relatively unimportant (5). From a practical standpoint, the increased complexity and loss of area for given overall dimensions weigh heavily against non-rectangular planforms. The high C_L values of model J mod 1 (seen in figure 45) indicate that minor rounding of the corners along with a reduction in aspect ratio may have a beneficial effect when compared with model A mod 1 (figure 47) where only aspect ratio was changed.

Effect of slots

The advantage of a slotted door should be twofold. In effect, one achieves two foils of higher aspect ratio than the overall model. The forward foil can also be used to direct the flow over the suction side of the after foil, thereby delaying seperation and loss of lift.

Figure 40 compares the original model with the two slotted models. Improved performance at high angles of attack is seen, as anticipated. Model L, in which the slot is located at the quarter chord, maintains a lift coefficient greater than 1.3 to angles of attack over 45 degrees.

Modifications to the slotted models (figures 48 and 49) indicate some benefit from corner rounding. Model L mod 1 shows higher lift coefficients in the range between 25 and 45 degrees. Model K mod 2 showed a similar but less pronounced effect. The change in C_L values with aspect ratio was similar to that seen in unslotted foils except there was no significant effect on delay of stall.

Effects of Reynolds Number

All tests were conducted at a tunnel velocity of 20 feet per second, which corresponds to a Reynolds Number of close to one million for the 6 inch models. Full scale doors operate in the range of two to three million. Hydrodynamically, this represents little difference, as significant effects on performance are usually seen only with order of magnitude changes in Reynolds Number.

Evaluation of designs tested

Existing trawl boards have a normal angle of attack between 40 and 45 degrees, corresponding to a lift coefficient of around .83 and drag coefficient of .80 (2,3,15). These values can be used as a standard of comparison to determine what benefits might be obtained by the adoption of one of the designs here tested.

The highest L/D values for these models tend to occur at angles of attack of around zero. The low lift coefficients of a board operating at this angle would require a tremendous area in order to provide the necessary trawl spreading force. The steep slope of the C_L curve in this range would cause major variations in lift for small perturbations of angle. Lack of accurate control of trawl board angle of attack means that these regions of rapid change in lift coefficient must be avoided.

Table 2 is a comparison of the common flat trawl board with the models tested. Comparing the value of C_L from above with that of the new designs, area requirements of the new boards can be determined. Using this area and the ratio of the two drag coefficients, the resultant drag is obtained, as a percentage of the old door's drag.

TABLE 2 Size and Drag Predictions from Test Results

Model	C_L max	C_D @ C_L max	Size	Drag	C_L	C_D avg	15 Degree Range Angle	15 Degree Range Size	Drag
Orig	1.34	.37	.62	.29	1.16	.425	13 to 28	.72	.38
D	1.08	.25	.77	.24	.97	.36	11 to 26	.86	.39
A	1.33	.34	.62	.27	1.21	.43	12 to 27	.69	.37
A mod 1	1.47	.79	.56	.56	1.32	.67	22 to 37	.63	.53
G	1.41	.40	.59	.29	1.22	.405	8 to 23	.68	.34
E	1.16	.70	.72	.63	1.09	.385	12 to 27	.76	.37
E mod 1	1.22	.74	.68	.63	1.00	.36	11 to 24	.83	.37
I	1.40	.38	.59	.28	1.20	.405	10 to 25	.69	.37
J	1.24	.30	.67	.25	1.17	.42	11 to 26	.71	.37
J mod 1	1.47	.73	.56	.52	1.32	.65	21 to 36	.63	.51
C	1.08	.54	.77	.52	*	*	*		
C mod 1	.97	.60	.86	.64	.86	.535	24 to 39	.97	.65
H	1.07	.61	.78	.59	.93	.555	23 to 38	.89	.62
H mod 1	.91	.52	.91	.59	..84	.53	24 to 39	.99	.65
F	.97	.50	.86	.53	.82	.30	12 to 27	1.01	.38
F mod 1	.87	.35	.96	.42	.74	.31	16 to 31	1.12	.43
B	1.04	.63	.80	.63	.92	.33	14 to 29	.90	.37
B mod 1	.98	.30	.85	.32	.88	.355	18 to 33	.94	.42
K	1.37	.85	.61	.64	1.09	.395	15 to 30	.76	.38
K mod 1	1.18	.79	.70	.69	1.00	.395	17 to 32	.83	.41
K mod 2	1.23	.80	.67	.67	.97	.445	19 to 34	.86	.48
L	1.38	.97	.60	.73	1.29	.52	20 to 35	.64	.42
L mod 1	1.47	.93	.56	.66	1.27	.54	21 to 36	.65	.44
L mod 2	1.37	.92	.61	.70	1.20	.56	23 to 38	.69	.48
Flat Plate	1.08	.70	.77	.67	.88	.595	23 to 38	.94	.70

*Insufficient data

Two comparisons are made, one with the new door operating at its value of C_L max and another assuming a 15 degree range for angle of attack. In the latter method, the range was selected in a favorable position, however, the minimum value of C_L in the range and the average value of C_D in the range were used for comparison. This method should present a conservative estimate of any potential benefits.

Implications beyond the designs tested

The high lift coefficients generated by models G and I suggest additional gains from even higher camber. One aerodynamic study (7) found increases in C_L for camber up to nearly 20 percent. The drag in this extreme case would probably be prohibitive but intermediate values such as 15 to 16 percent could prove advantageous.

The insensitivity to thickness presents the possibility of the degenerate case of a single curved plate. The bracing required to maintain the rigidity of such a door would detract from the otherwise simple design. The leading edge of the door, subject to much abuse, would require substantial reinforcement which would obstruct the flow in this critical area. The possibility remains real but would require further testing.

The relatively poor performance of the models with flat pressure surfaces negates the possible economies in their fabrication. This could be due to the low camber of these models, however, to obtain higher camber would produce an extremely thick profile of awkward geometry and higher form drag.

The slotted models (K,L) performed well in the higher ranges of angle of attack. The slot location was selected arbitrarily and turned out to be an important factor. The better performance of model L favors the 25% of chord location but it is unlikely that an optimum has been reached. Also of importance is the relative location of the forward and after foils. Further study is required to extract the full potential of this configuration.

The higher lift coefficients of models A mod 1 and J mod 1 indicate similar results might be produced by lower aspect ratio modifications of the other highly cambered models. Reduction of aspect ratio beyond those values tested deserves consideration.

Potential impact on trawling productivity

The successful development and adoption of one or more of the better trawl board designs tested here would have a significant effect on the economics of trawling. A complete economic analysis is beyond the scope of this paper, but to demonstrate the effect, the following crude analysis is presented.

A design having one of the best overall characteristics is model G. The high lift of this configuration would allow replacement of the existing trawl door with one 68% as large, i.e., a 4' by 8' flat door could be replaced by a new design 4'8" by 4'8". This door would provide the same spreading forces to the trawl net but have only 34 percent of the drag. The trawl boards account for approximately 35 percent of the total trawl system resistance; the trawl net contributing 55% (13). Therefore, the total reduction of trawl system resistance would be 23%. Here it is assumed that there is a proportional decrease in sea bed friction of the trawl boards (likely since the wide shoe and lower angle of attack should significantly reduce the normal plowing effect). The fisherman would now have 3 possible options for capitalizing on this situation.

1) If he is satisfied with the catch rate of his trawl, he can simply tow at his normal speed using a lower engine r.p.m. and realize immediate fuel savings. Depending on the distance to the fishing ground, most vessels could see a 15 to 20 percent reduction in fuel consumption.

2) The fishermen could increase his catch with low drag boards by towing faster. The assumptions above, plus the fact that required horsepower varies with V^3, yield a towing speed $(1/.77)^{1/3}$ of the original. Thus, with the new doors, the same trawl net and same fuel consumption, the towing speed can be increased by over 9%. Therefore, 9% more ground can be covered in the same towing time, yielding a proportional increase in catch size. Certain inevitable changes in trawl geometry are neglected here as they are difficult to predict quantitatively. Also neglected are the beneficial effects of increased propeller propulsive coefficient and possible reduced fish escapement with faster towing speeds.

3) The final possibility is to use the resistance saved with the low drag to tow a bigger net. Using laws of hydrodynamic scaling and assuming geometric similarity, it can be shown that a net with 34% more frontal area could be used. For example, a fisherman using the 4' x 8' flat doors and a trawl net with a 70' head rope length could use low drag doors 5'5" x 5'5" and a net of 81' head rope length.

   Ground fish catch can be approximated as a linear function of head rope length (16) and this larger trawl system could yield 16% more bottom species. Catch size of off bottom fish is roughly a function of the net frontal area and would therefore increase by 34%.

Figure 51 is a bar graph of the possible increase in productivity by using one of these options. It should be remembered that the catch size and its selling price represents the only source of a fisherman's income, whereas, fuel costs are only a part of his total expenses. For this reason, option 3 is most desirable provided the vessel and its deck equipment will allow the bigger net.

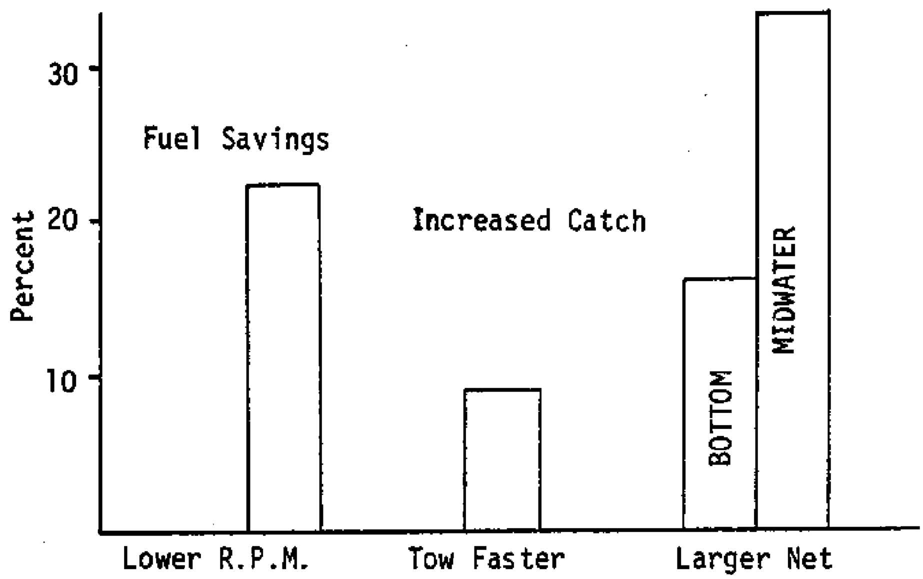


Figure 51. Potential economic impact

PROTOTYPE SEA TRIALS

Testing of the original Sea Grant configuration began in the late spring of 1977 using 5' x 5' prototype trawl boards. The 86' side trawler "Vincie N" out of Gloucester, Massachusetts, was used for this initial deployment.

The prototypes were constructed as shown in Figure 1 and were exact mirror images, and each weighed 920 pounds. However, one door performed well and the other dragged along on its back, defying attempts to right it. The side trawler rig made it difficult to access the problem as, while the trawl boards are within view, the vessel must be in a tight turn towards the gear to keep the after board out of the propellor.

A more suitable vessel, the stern trawler "Cap'n Bill V" out of Woods Hole, Massachusetts, used the prototype boards during the summer of 1977. Though more successful, their experience was also sporatic with one of the boards occasionally upsetting without an apparent explanation. During these trials, various adjustments were made to the attachment points to alter angle of attack and the vertical location of the towing point. The effects on board behavior of these adjustments were generally as expected however the overall stability problem was not solved.

The testing aboard both the Vincie N and the Cap'n Bill V was during actual commercial fishing operations. Little compromise was made for research purposes and trials were conducted using normal fishing techniques.

During the spring of 1978 a pair of 4' x 4' prototypes were fabricated weighing 400 pounds. These boards were designed for use aboard the research vessel A.E. Verrill of Woods Hole. This stern trawler was equipped with a small commercial trawl system but was chartered and therefore unencumbered by the pressures of commercial fishing. Comparisons were made between the 6' x 40" wooden trawl boards normally used by the vessel and the new boards. Though the prototype had 20 percent less area the divergence of the towing warps measured the same as with the conventional boards. Thus the higher lift coefficient of the new boards predicted in the model tests was roughly substanciated.

Due to extra care being taken during the lowering of the trawl system to the bottom fewer problems were encountered with board stability. Attempts at a total remedy of the problem by installing buoyancy spheres inside the upper chamber failed to have a significant effect. The cause of the instability was not completely understood. When the same prototype boards were later used aboard the commercial stern trawler "Everfree" out of Gloucester the instability again became troublesome.

UNDERWATER VIDEO OBSERVATIONS

In the normal use of trawl boards there are few immediate clues to their behavior and attitude during use. The divergence of the towing warps indicate whether adequate sidewards spread is being provided. Usually the cables themselves transmit vibrations from the boards dragging along the seabed. Unequal tension in the tow cables can indicate a problem but usually the best clue is to observe the abrasion marks on the board's shoe when retrieved after the tow.

Experimenting with trawl boards at sea without remote sensing devices is difficult at best. The use of sensor recording or telemetry has been used in trawl system studies (2,15) but these techniques are usually considered too complicated for commercial operations. Diver observation is another common method (17,18) but due to the risks can be safely used only under controlled, non-commercial operations.

The use of video equipment for trawl observation is becoming more common and this method was employed to study the behavior characteristics of the new doors. In cooperation with the Marine Fisheries Program at the Massachusetts Maritime Academy a technique was developed to observe a small trawl system equipped with conventional and prototype boards. An area of consistently shallow and unfouled bottom was selected. A towing vessel pulled both the trawl system and an observation boat. From the observation boat a hand directed video camera was controlled. A video cassette recorder was used while the position of the observation boat relative to the trawl system was controlled by adjusting the boats tow bridle.

The Effect of Tidal Currents on Trawl Boards

Tows were made at various speeds and directions relative to the tidal current. The mechanism of instability soon became clear. The effect of tidal currents on trawl system behavior depends upon the relative current velocity and direction. When towing against a current the speed made good over the seabed is reduced. When towing with a fair tide the speed made good is increased. When towing at an angle to the current the trawl system encounters the seabed from a direction other than straight ahead.

The stability of trawl boards in bottom fishing is somewhat dependent on seabed contact. While being lowered to the bottom, the trawl boards, due to their weight, assume an outward tilt as view from ahead. When they reach the seabed the contact friction under normal conditions reacts to push the shoe outward tilting the board inward. This change in attitude directs the hydrodynamic thrust slightly upward, lessening the bottom friction and generating stability.

When the progress over the bottom differs from straight ahead this balance is upset. In particular, when the angle between the course made good and the trawl heading approaches or exceeds the board's angle of attack this stability mechanism disappears. Figure 52 shows the effect of a 2 knot tide from abeam on a trawler towing at 3 knots. Under these conditions, the part prototype trawl board would fall on its back while the starboard board would remain operating.

The key difference between the new and conventional wooden board is the angle of attack, as shown in figure 53. Under the same conditions as above the wooden trawl board, due to its high angle of attack, would remain stable. The lack of stability encountered with the prototypes would therefore likely exist with any design utilizing the relatively new low angle of attack.

Table 3 was developed to show the effect of various towing speeds and current speeds and directions. From an efficiency standpoint the optimum angle of attack for the prototypes is around 18 degrees. From the table it can be determined under which conditions they would operate properly. Notice also that there are several cases where even conventional boards would upset.

Aside from the possibly detrimented effect on trawl boards while trawling in a crosstide, there are other drawbacks revealed in this table. Fish catch is, while bottom trawling, proportional to the area swept between the trawl boards. When being set at an angle as in figure 54 the effective swept area is reduced. This value is presented in the table as a percent of the normal, no current, situation. The effective swept area multiplied by the effective change in speed due to the current is also presented. The worst conditions for trawl board stability are also seen to be the worst from a catch productivity standpoint.

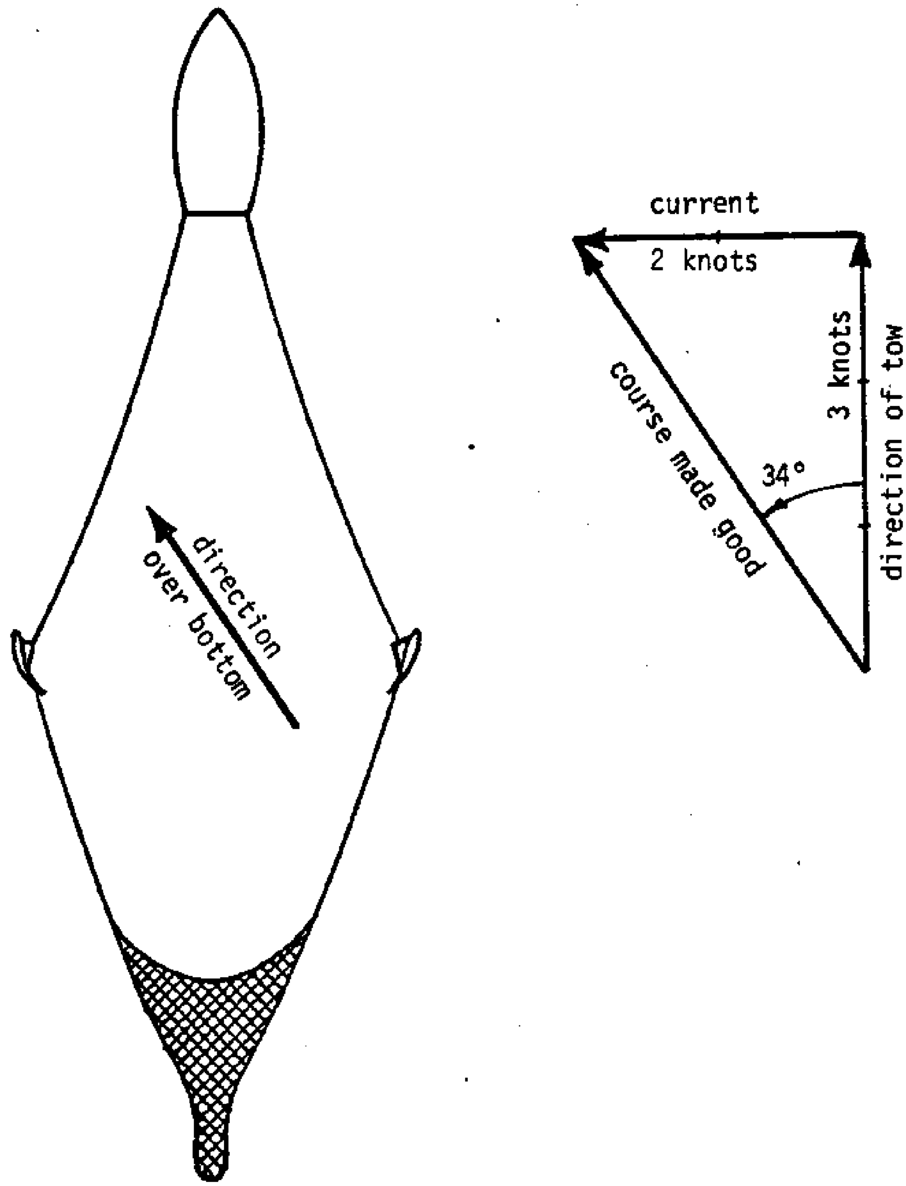


Figure 52. The effect of a 2 knot crosstide

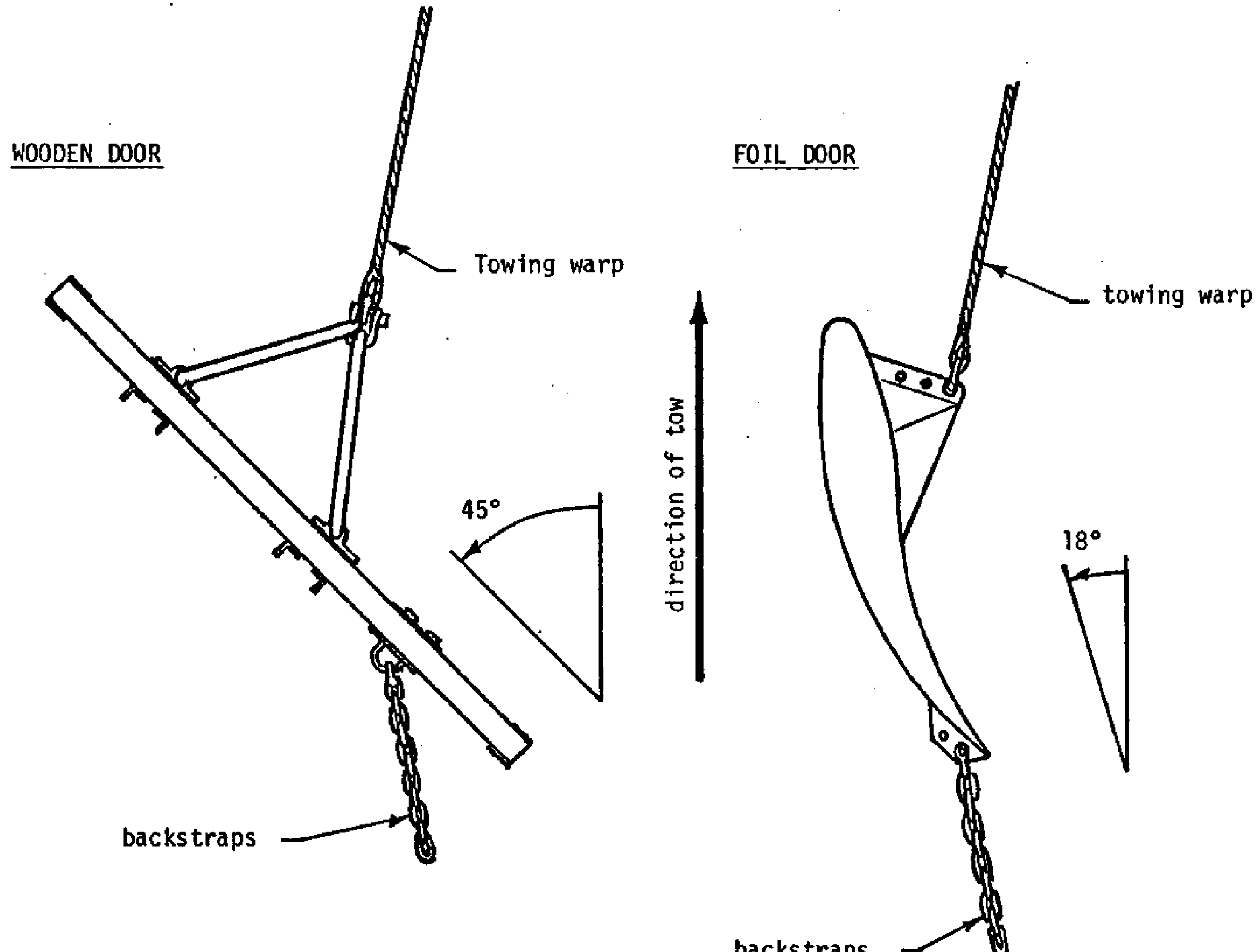


Figure 53. A comparison of the angle of attacks of conventional wooden trawl boards and the prototype trawl board.

Using vessel speed in knots, current speed in knots, and current direction relative to vessel heading, the following can be obtained:

Trawl direction = the direction of travel relative to course steered
Trawl speed = speed over bottom in knots
Effective swept area = percent compared to normal
Ground covered = effective swept area x trawl speed compared to normal

Vessel Speed (Knots)	Current Speed (Knots)	Relative Current Direction (Degrees)	Relative Trawl Direction (Degrees)	Trawl Speed (Knots)	Effective Swept Area (Percent)	Ground Covered (Percent)
3	1	stern	0°	4	100	133
		45°	11°	3.8	98	124
		90°	18°	3.2	95	100
		135°	17°	2.4	96	77
		stem	0°	2	100	67
	2	stern	0°	5	100	166
		45°	18°	4.6	95	146
		90°	34°	3.6	83	100
		135°	42°	2.1	74	52
		165°	25°	1.2	91	36
		stem	0°	1	100	33
	2.5	stern	0°	5.5	100	183
		45°	20°	5.1	94	160
		90°	40°	3.9	77	100
		135°	55°	2.1	57	40
		165°	48°	.87	67	19
		170°	23°	.55	92	17
		stem	0°	.5	100	17
4	1	stern	0°	5	100	125
		45°	8°	4.7	99	116

Table 3. The effects of tidal current direction and velocity on bottom trawls.

Vessel Speed (Knots)	Current Speed (Knots)	Relative Current Direction (Degrees)	Relative Trawl Direction (Degrees)	Trawl Speed (Knots)	Effective Swept Area (Percent)	Ground Covered (Percent)
4	1	90°	14°	4.1	97	100
		135°	12°	3.6	98	88
		stern	0°	3	100	75
	2	stern	0°	6	100	150
		45°	15°	5.6	97	136
		90°	27°	4.5	89	100
		135°	29°	2.9	87	63
		stern	0°	2	100	50
	3	stern	0°	7	100	175
		45°	19°	6.5	95	154
		90°	37°	5	80	100
		135°	49°	2.8	66	46
		165°	35°	1.3	82	27
		stern	0°	1	100	25

Table 3. (continued)

A fisherman can, therefore, by taking into consideration the anticipated tidal currents, plan a tow to eliminate the possibility of trawl board instability and maximize the ground covered. If, however, the current conditions are unknown, or if the direction of tow is dictated by other factors, a proper angle of attack setting could be determined to insure performance. The prototype boards when adjusted to 30 degrees retain their advantage yielding half the drag of a conventional board.

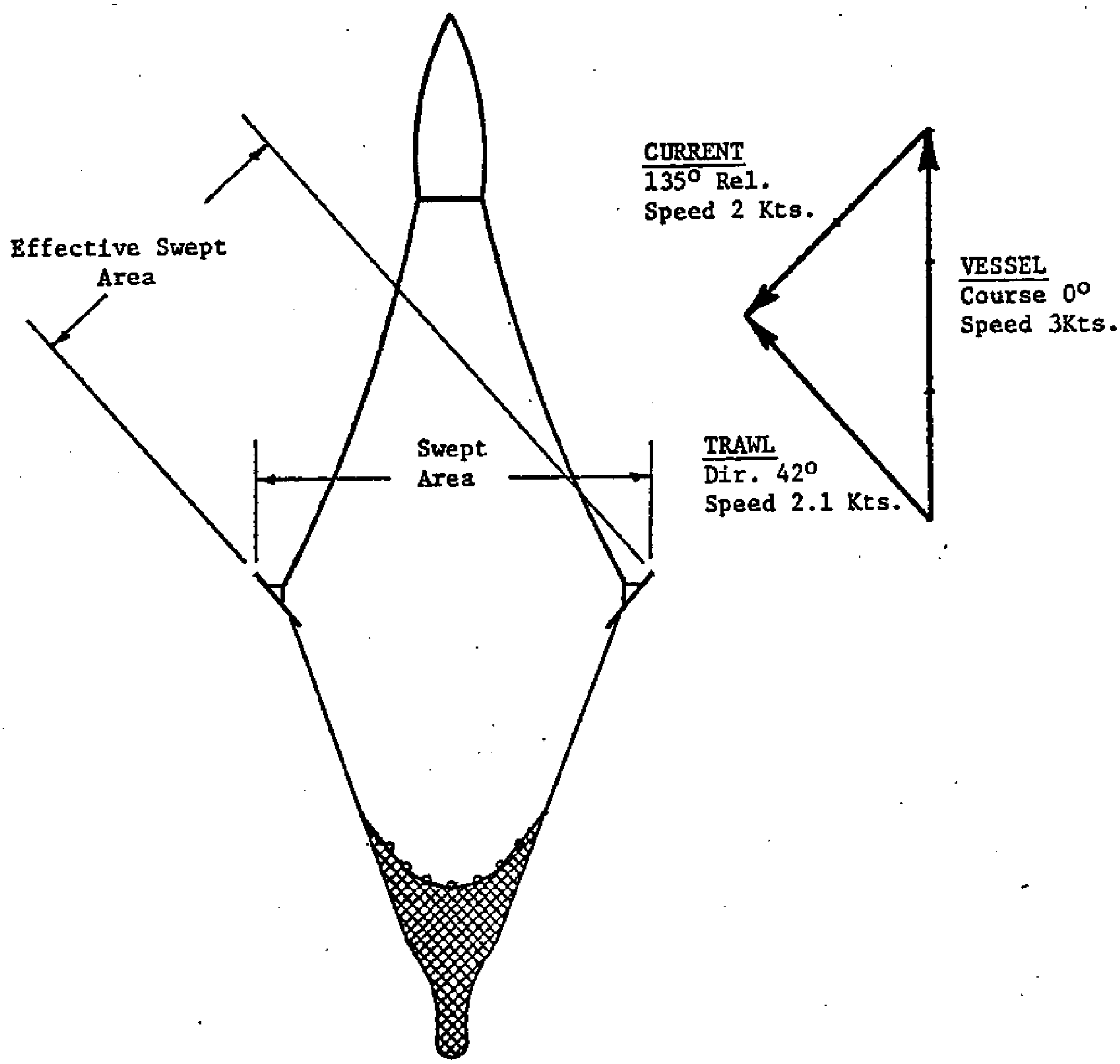


Figure 54. The effect of crosstides on swept area.

MIDWATER AND SHRIMP VERSIONS

Due to its relatively simple design (single panel suction and pressure surfaces) and good hydrodynamic performance, model J has been adapted to other trawl board designs. A high aspect ratio version has ben designed for Wharf Forging and Welding of South Boston, Massachusetts. Though common in foreign fishing fleets, single boat midwater trawling is only beginning to gain popularity in this country. The advantages of this technique are that due to the absence of bottom contact,twines in the trawl net can be finer and most midwater species can effectively be herded down the net by meshes they could readily swim through. Only the rear sections of the trawl and the codend need to be small meshes. The disadvantages are that midwater species tend to bring lower prices when landed and are generally schooling fish and vessels require sophisticated sonar detection equipment.

Trawl board requirements are very different in such an operation. Bottom contact is not a consideration and aspect ratio can be increased for improved efficiency. While trawling,the skipper must have the capability of rapidly adjusting the vertical location of the trawl net to intercept a school of fish detected by sonar. Midwater boards are therefore made sensitive to towing speed, rising with an increase and lowering with a decrease, thereby aiding in this maneuver. Figure 55 is a sketch of the design. Two pair have been constructed, a 3'4" x 10' version weighing 1100 pounds and 4' x 12' version weighing 1350 pounds. The former was delivered to a vessel in New Jersey and the latter to the "Judith Lee Rose" out of Gloucester, Massachusetts. No results have been received on either pair as of this writing.

A low aspect version of model J was designed as a shrimp trawl board for Thompson's Board Ship in Bayou La Batre, Alabama in cooperation with the Alabama Sea Grant Advisory Service. The low board weight requirement in this type of trawling resulted in aluminum being specified. The design is shown in figures 55 and 56. The list of materials is found in table 4. Prototypes have not yet been constructed.

Both these versions have the potential to significantly effect the efficiency of trawling operations. Midwater boards of foreign design have often employed high aspect ratio planforms. The sectional shape of the midwater design presented here should prove more efficient that the single curved plate commonly used, though no tests have yet been made. The double wall construction should provide a more rigid structure and allows the addition or removal of ballast without effecting the flow.

Shrimp trawling has one of the worst ratio of protein yield verses fuel expended of any major fishery in the U.S. The shrimp trawl boards used by these vessels are also the least efficient. Shrimp trawling is usually done on far smoother bottom and encounters relatively weak tidal currents. The application of the aluminum version shown here or a similar light weight steel version should adapt readily to the fishery. Such an improvement would be truly beneficial to an industry so heavily affected by fuel cost.

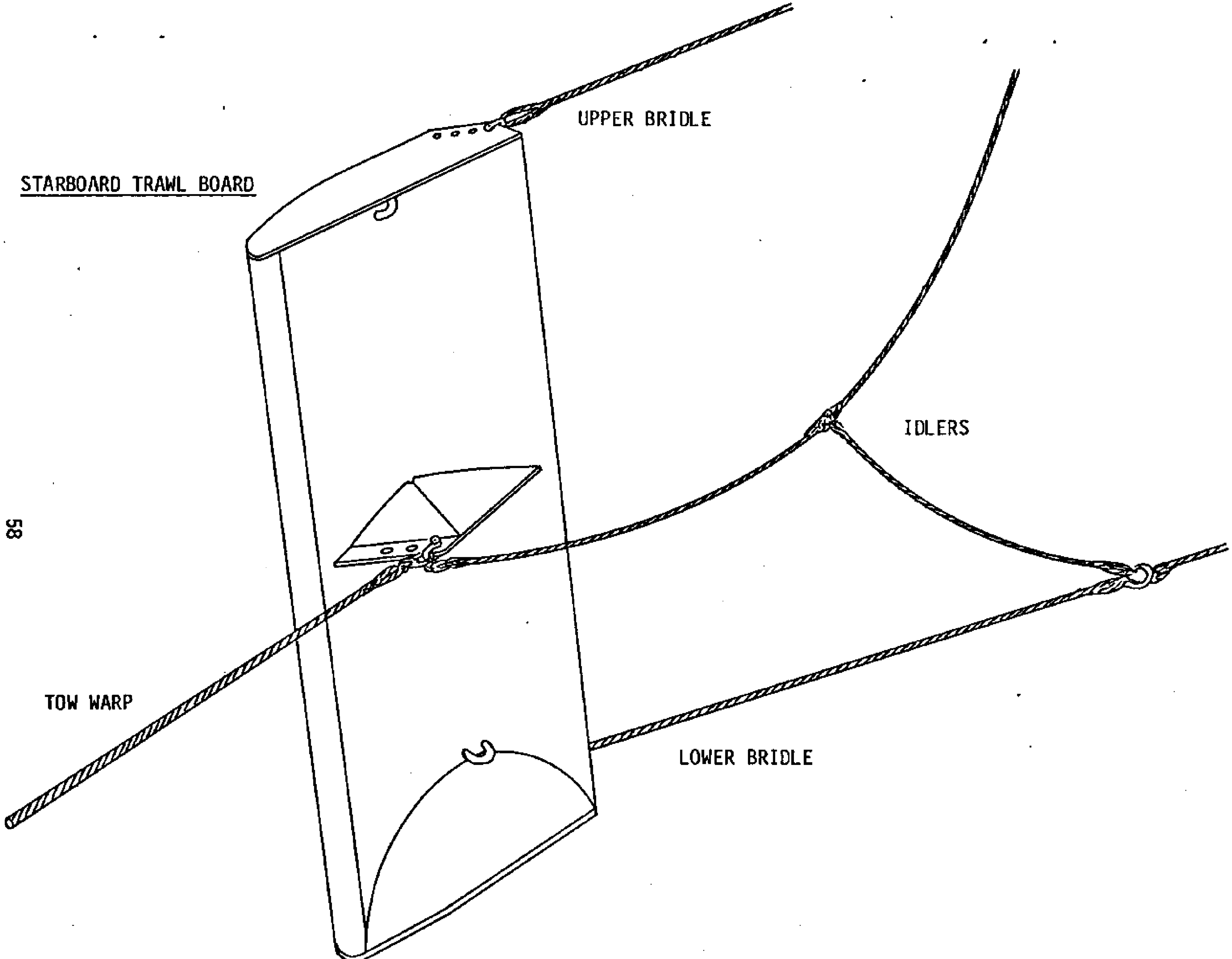


Figure 55. Midwater trawl board

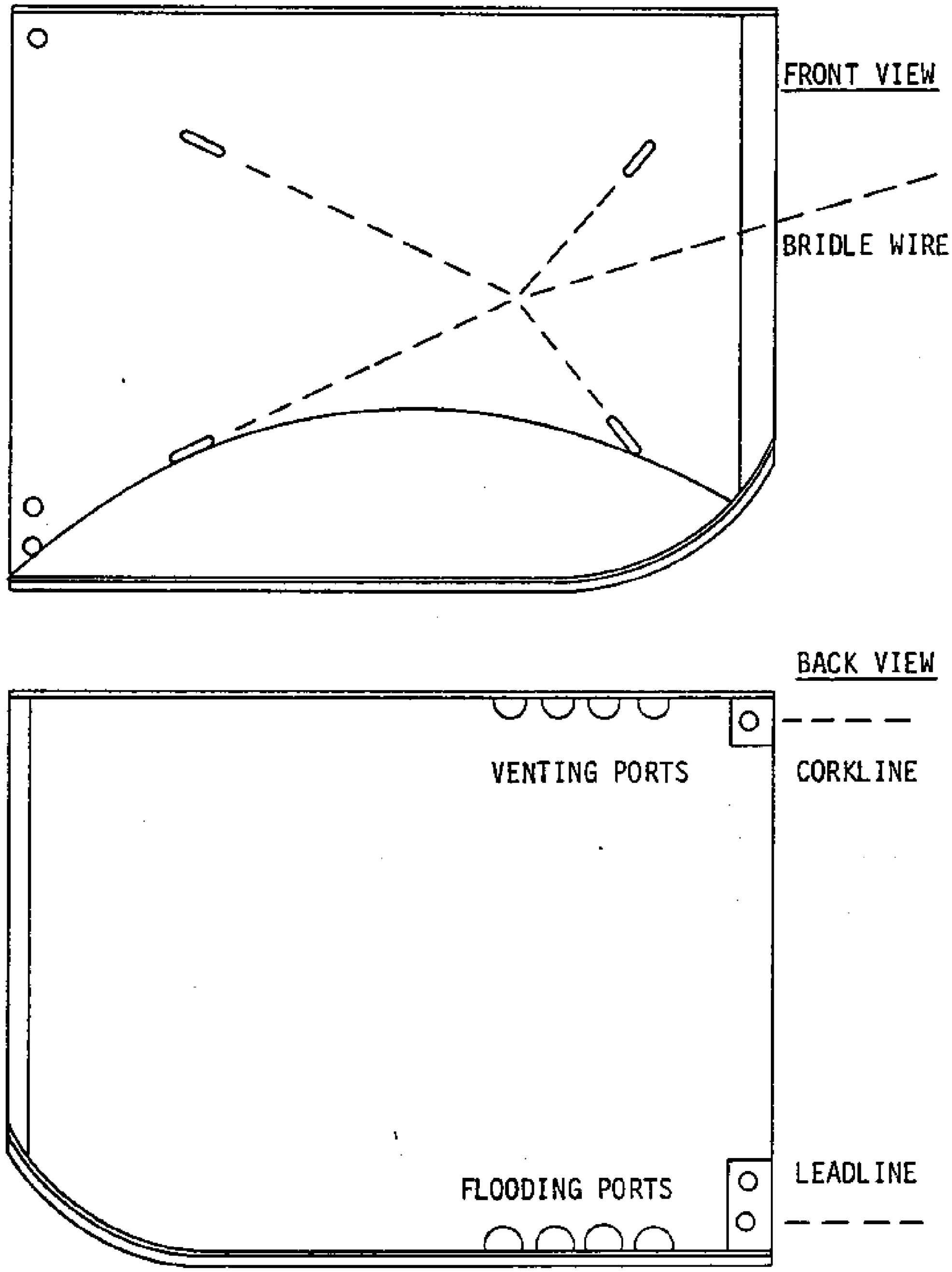


Figure 56. Shrimp trawl board.

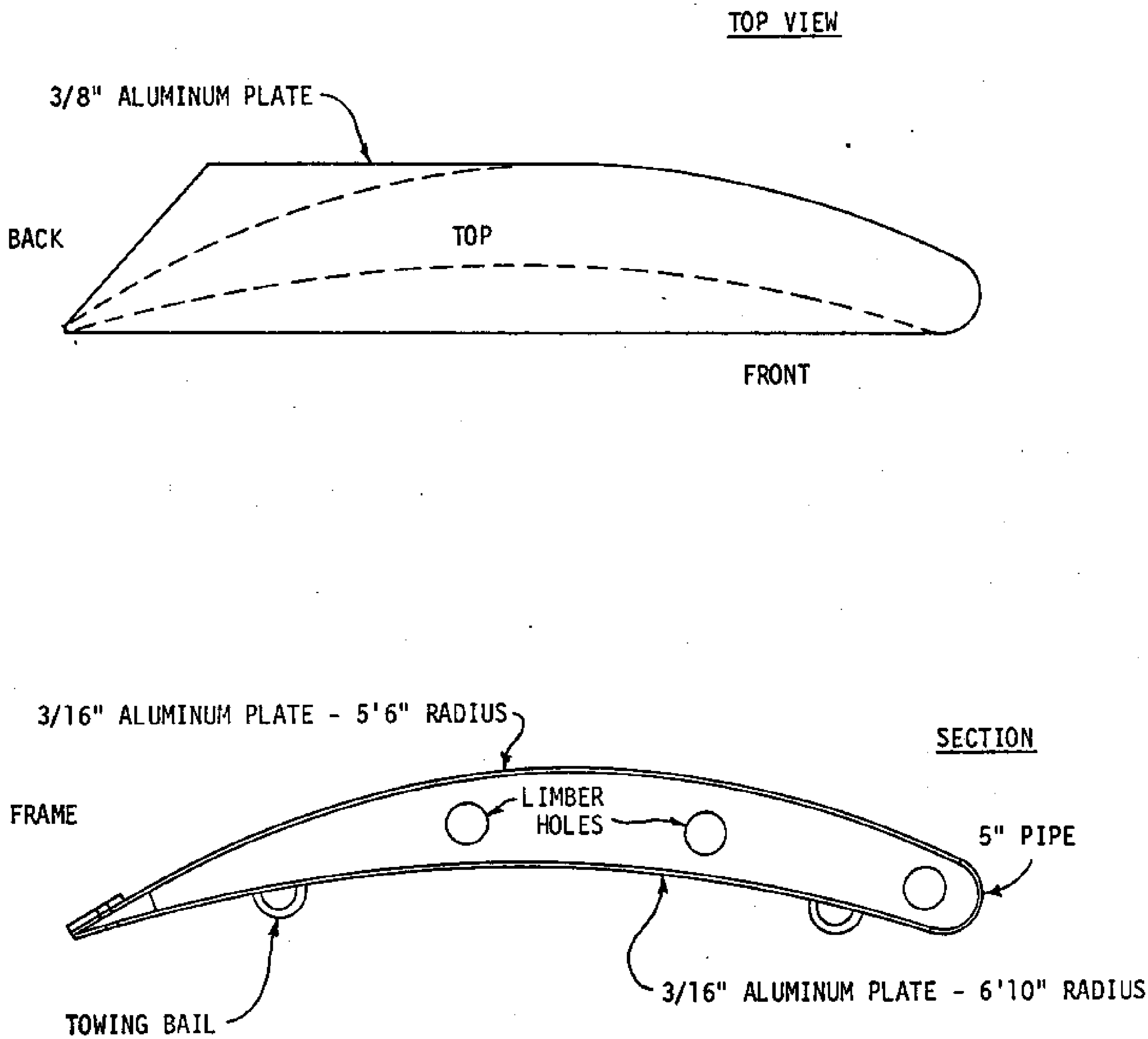


Figure 57. Shrimp trawl board, top view and section.

5'6" x 49" Cambered Aluminum Trawl Boards

TABLE OF WEIGHTS

DESCRIPTION	MATL.	DEM.	WEIGHT
Pressure Surface	6061	3/16" x 48" x 64"	56.5
Suction Surface	6061	3/16" x 48" x 67"	59.2
Top Plate	6061	3/8" x 11" x 66"	21.8
Bottom Plate	6061	3/8" x 11" x 70"	22.5
Upper Frame	6061	3/16" x 11" x 60"	6.6
Lower Frame	6061	3/16" x 11" x 60"	6.6
Runner Fillet Plate	6061	3/16" x 15" x 63"	12.7
Nose Pipe	6061	.258" x 5.563" O.D. x 42"	9
Corkline Rein.	6061	3/8" x 4" x 4"	.6
Leadline Rein.	6061	3/8" x 4" x 8"	1.2
Tow Bails (4)	6061	3/4" x 6"	1
Shoe (Steel)	1020	5/8" x 11" x 70"	124
Ballast	1020	100 pounds steel scrap	100
			421.7

Weight under water = Al x .62 x Fe x .87

= 197.7 x .62 + 224 x .87

= 317 pounds

Table 4. Materials list for 5'6" x 49" cambered aluminum trawl board.

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