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NAVY DEPARTMENT
THE DAVID W. TAYLOR MODEL BASIN
AERODYNAMICS LABORATORY
WASHINGTON 7, D.C.

PRELIMINARY STUDY OF HOVER PERFORMANCE OF A RAM-WING GEM

by

Gerald R. Barlow and Richard G. Huntington

October 1962

Report 1662

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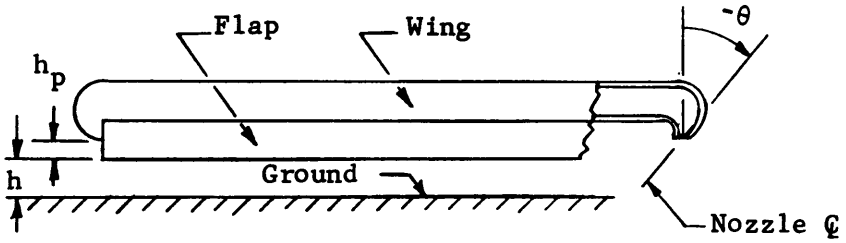
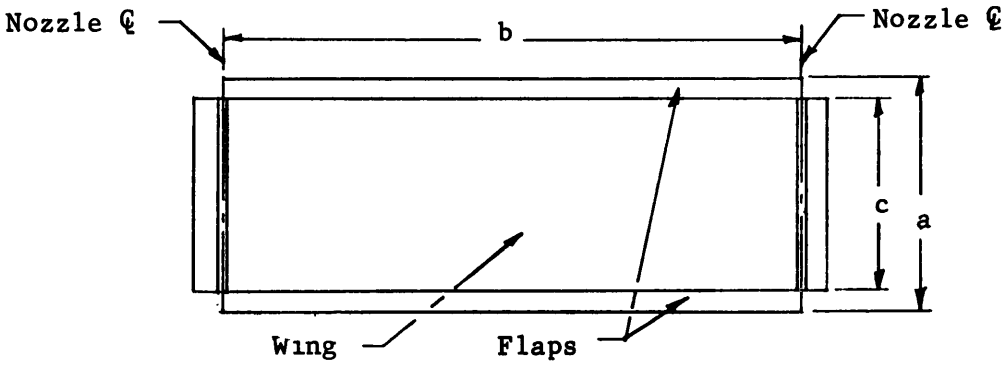
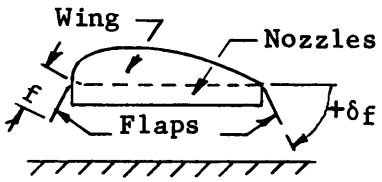
NOTATION



Front View



Bottom View



Side View

SYMBOLS

a	distance between flap tips in feet
A	augmentation factor (ratio of total lift experienced by the model to the total jet momentum flux; A = L/J)
AR	aspect ratio (b/c)
b	wing span (distance between nozzle center lines) in feet
c	wing chord in feet
C	perimeter in feet, measured along nozzle center lines and flap tips [2(a+b)]
S_b	base area in square feet
f	flap chord in feet
h	altitude in feet, measured from the ground to the lower edge of the flap
h_p	distance from lower edge of flap to nozzle exit
J	jet momentum flux in pounds
L	total lift in pounds
p	supply air gage pressure in pounds per square inch
δ_f	flap angle in degrees measured from wing chord line, positive for downward flap deflection
θ	jet-discharge angle in degrees, measured from vertical at nozzle exit; negative for an inward-inclined jet

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AERODYNAMICS LABORATORY
DAVID TAYLOR MODEL BASIN
UNITED STATES NAVY
WASHINGTON, D. C.

PRELIMINARY STUDY OF HOVER PERFORMANCE OF A RAM-WING GEM

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Gerald R. Barlow and Richard G. Huntington

SUMMARY

The results of hover tests of a rectangular planform ram-wing ground-effect machine, utilizing wing-tip jets and leading-edge and trailing-edge flaps are presented. Several parameters were studied to determine optimum configurations for future ram-wing designs.

The effects of aspect ratio, flap chord length, flap deflection angle, and jet nozzle angle were investigated. The results are presented as plots of augmentation factor versus ground proximity parameter. The results obtained indicate that for the configurations tested, the largest aspect ratio, the smallest flap chord length, and the smallest flap deflection angle give the lowest value of ground proximity parameter for a given augmentation. The optimum jet nozzle angle is between -60° and -72°.

INTRODUCTION

Investigations, both theoretical and experimental (References 1 and 2), have demonstrated the possibility of using a wing in ground

effect as an air-cushion vehicle. Although the advantages of such a vehicle are evident, no quantitative experimental results have been published to date. One of the questions that arise in the study of such a vehicle is possible modification to provide hovering capability.

The present investigation was conducted to study parameters that determine the hover performance of a ram-wing GEM incorporating wing-tip jets and leading-edge and trailing-edge flaps. The tests were conducted in the Subsonic Division of the Aerodynamics Laboratory at the David Taylor Model Basin during the period from June 1, 1960 to August 22, 1960.

MODELS AND APPARATUS

The models and apparatus used in the test were similar to those of Reference 3. The models were kept as simple as possible so that the following variables could be introduced readily:

(a) Jet discharge angle, θ

(b) δ_f

(c) Flap chord, f

(d) Aspect ratio

A schematic diagram of the entire test setup is given in Figure 1. The models (Figure 2a) were made of aluminum plate. All models had a wing chord, c, of 7 inches, and the AR's of the three plates tested were 1, 2, and 3. For each model there were three sets of full-span aluminum sheet flaps which represented 10, 20, and 30 percent of the wing chord. The flaps were bolted to hinged plates on the leading and trailing edges of the model. Plates on the wing tips served as supports for the five nozzles on each wing tip. The plates were hinged to permit changes in the jet angle, θ. (A sketch of a typical nozzle is shown in Figure 3.)

All the models had a one-inch-diameter rod at the center (Figure 2), which served as a guide for the adjustable or floating ground board. The ground board (Figure 2b) is an aluminum disc 3.5 feet in diameter. It was counterbalanced using a low-friction pulley system (Figure 1) to allow for the variation of effective ground board weight (lift).

PROCEDURE

For each combination of θ, δ_f, $\frac{f}{c}$, and AR, the augmentation factor A was varied, and the resultant altitude h was measured (Table 1). From the value of h determined and the values of area S_b and perimeter C measured for each configuration, the ground proximity parameter $\frac{4S_b}{hC}$ was determined. Values of A from 1.2 to 10.0 were obtained. For values of A less than 4, a ground board weighing 3 pounds was used. The ground board was made to weigh 10 pounds for values of A from 4 to 10.

Aspect ratios of 1, 2, and 3 were tested, each with full-span flaps of 10, 20, and 30 percent of the wing chord. Values of δ_f were 15°, 30°, 45°, and 60°. For the model with an aspect ratio of 3, values of θ of -30°, -45°, and -60° were used. For the other two models, θ had values of -45°, -60°, -65°, and -72.5°.

RESULTS AND DISCUSSION

The test results are presented in nondimensional form as plots of augmentation factor A versus ground proximity factor $\frac{4S_b}{hC}$ for various values of θ, $\frac{f}{c}$, δ_f, and AR. Definitions and symbols used are given in the notation. It is felt that the results are a good indication of the general relationship between the various parameters investigated. The effects of the four parameters on augmentation are shown in Figures 5, 6, and 7. Figures 8, 9, and 10 are typical cross plots showing the

effects of AR, $\frac{f}{c}$, and δ_f, respectively. All three of these parameters were found to have a marked effect on the value of $\frac{4S_b}{hC}$ for a given augmentation. An aspect ratio of 3 appears to be the best of those tested, with 2 and 1 following in that order. Of the three values of δ_f tested, 15° is most desirable. The most effective flap chord length tested is 10 percent of the wing chord. There is very little difference in effectiveness of jet deflection angle between -60° and -72.5°. Angles of -45° and -30°, however, generally give poor results.

CONCLUDING REMARKS

The test results for a ram-wing GEM model in hover having leading-edge and trailing-edge flaps and wing-tip jets indicate that the following values of the parameters studied give the most satisfactory results;

Aspect ratio	3
$\frac{f}{c}$	0.1
δ_f	15°
θ	-60° to -72.5°

Aerodynamics Laboratory
David Taylor Model Basin
Washington, D. C.
October 1962

REFERENCES

1. Aerophysics Co. Translation From the Finnish of Two Patents and One Paper Describing T. J. Kaario's Early Work on Air-Cushion Vehicles (1932-1949). Wash., Nov 1959. 15 1 incl. illus. (Rpt. AR-595)

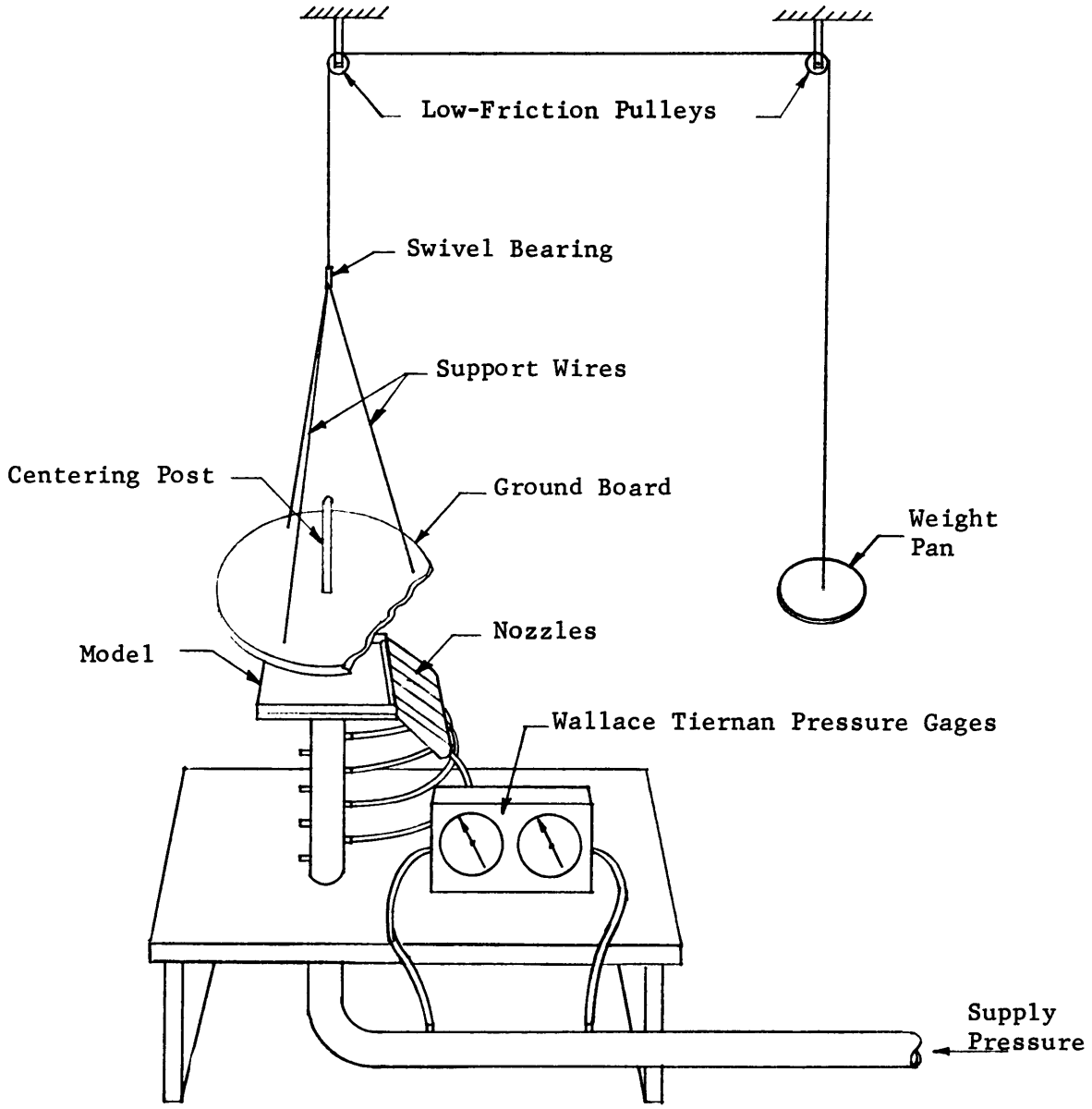
2. Kaario, Toivo J. The Principles of Ground Effect Vehicles. In Princeton Univ. Symposium on Ground Effect Phenomena; a Compilation of the Papers Presented, October 21, 22, 23, 1959. Princeton, Mar 1960. p. 253-262.

3. Tinajero, Anibal A. Static Behavior of a Rectangular Plan Form GEM Model Utilizing an Integrated System for Lift and Propulsive Thrust. Wash., Jun 1960. 25 p. incl. illus. (David Taylor Model Basin. Aero Rpt. 984)

Table 1

Nozzle Height With Respect to Ground

δ_f in degrees	f/c in percent	f in inches	h_p in inches
15	10	0.7	0.181
	20	1.4	0.500
	30	2.0	0.518
30	10	0.7	0.350
	20	1.4	0.707
	30	2.0	1.000
45	10	0.7	0.50
	20	1.4	1.00
	30	2.0	1.41
60	10	0.7	0.606
	20	1.4	1.212
	30	2.0	1.732

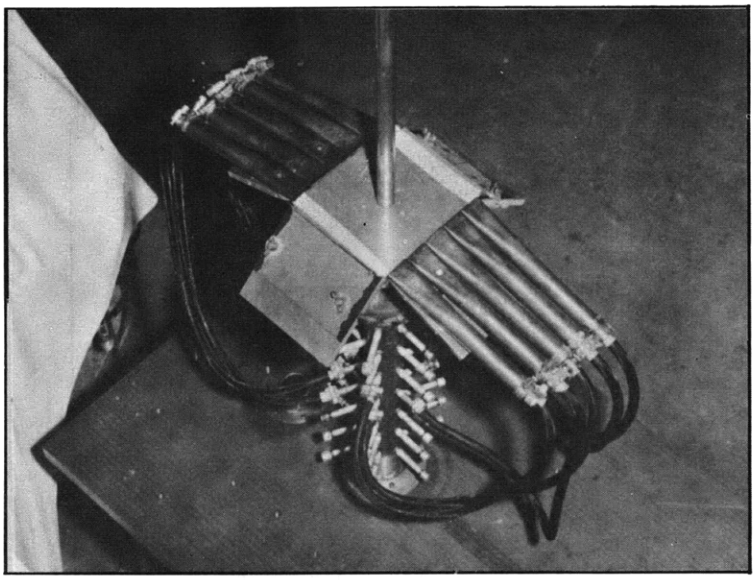


Note: Only one set of nozzles shown.

Figure 1 - Schematic Diagram of Test Setup

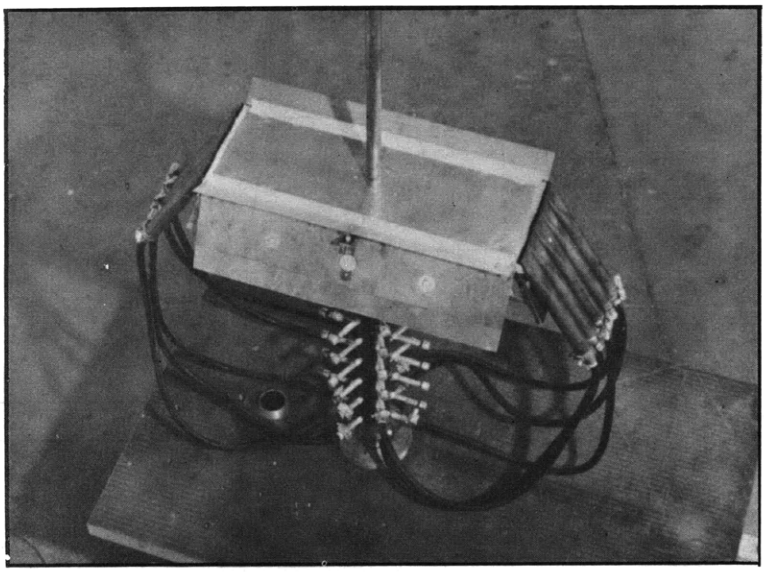
MLD, Sep 1962

FIGURE 1



PSD-300,618

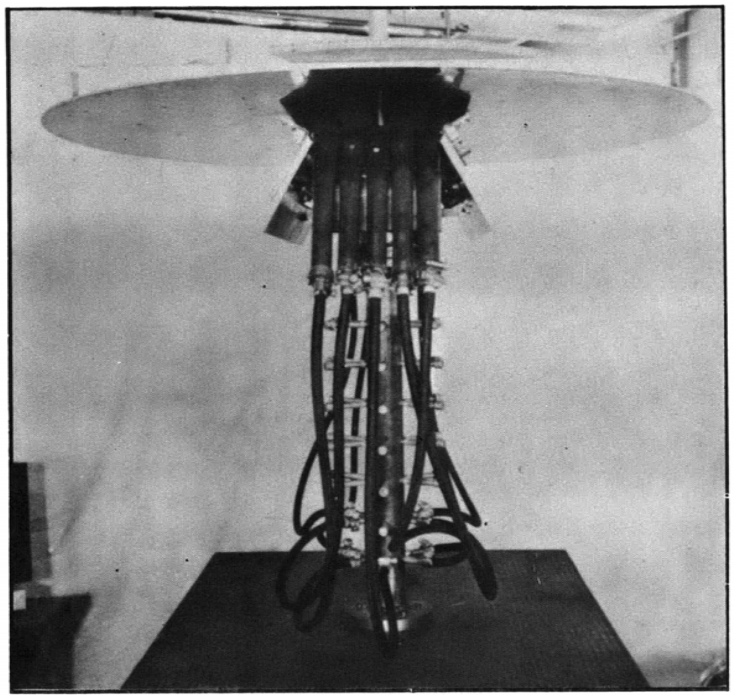
Aspect Ratio = 1



PSD-300,492

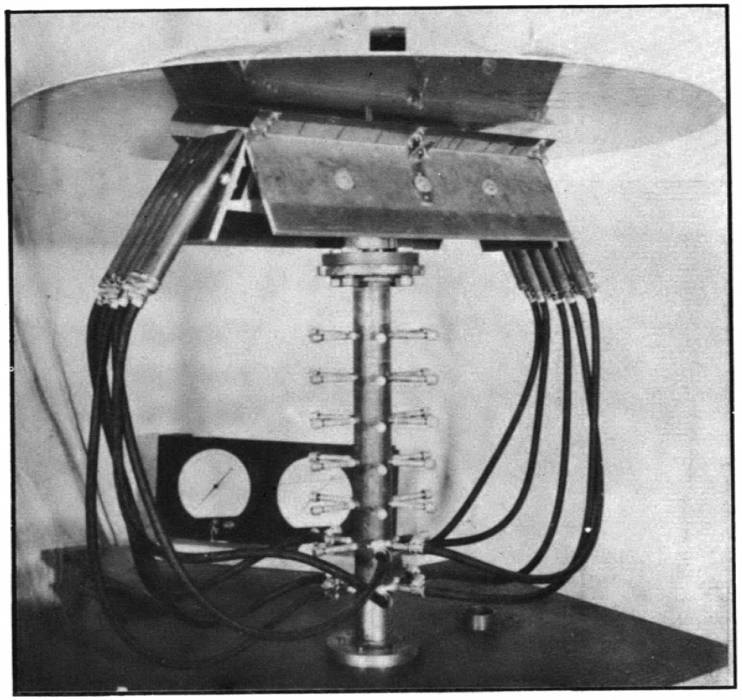
Aspect Ratio = 3

Figure 2 - Photographs of the Model and Test Stand
(a) Three-Quarter Top View, Ground Board Removed



PSD-300,494

Side View



PSD-300,616

Three-Quarter Front View

Figure 2 (Continued)

(b) Model With Ground Board

July 26, 1960

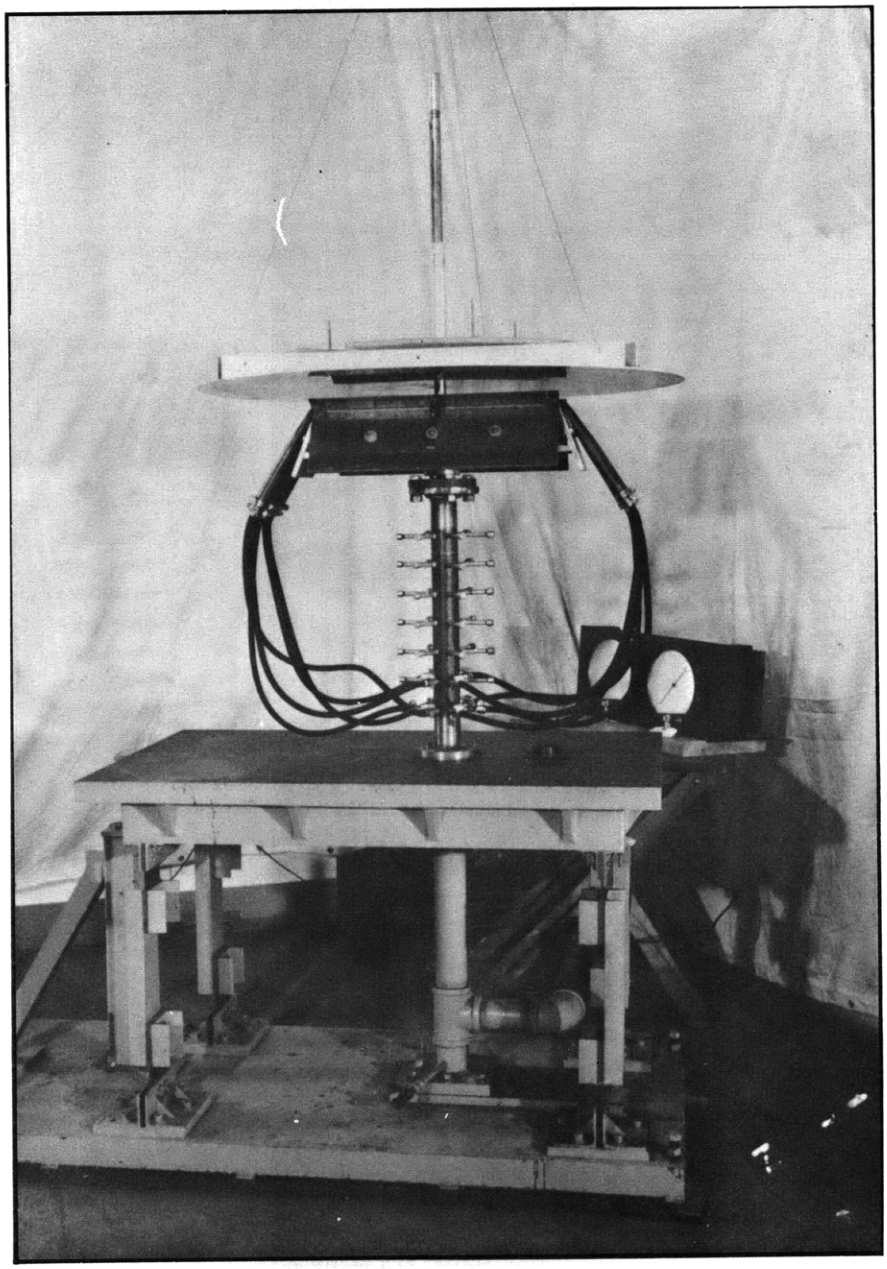


Figure 2 (Concluded)
(c) Complete Test Setup

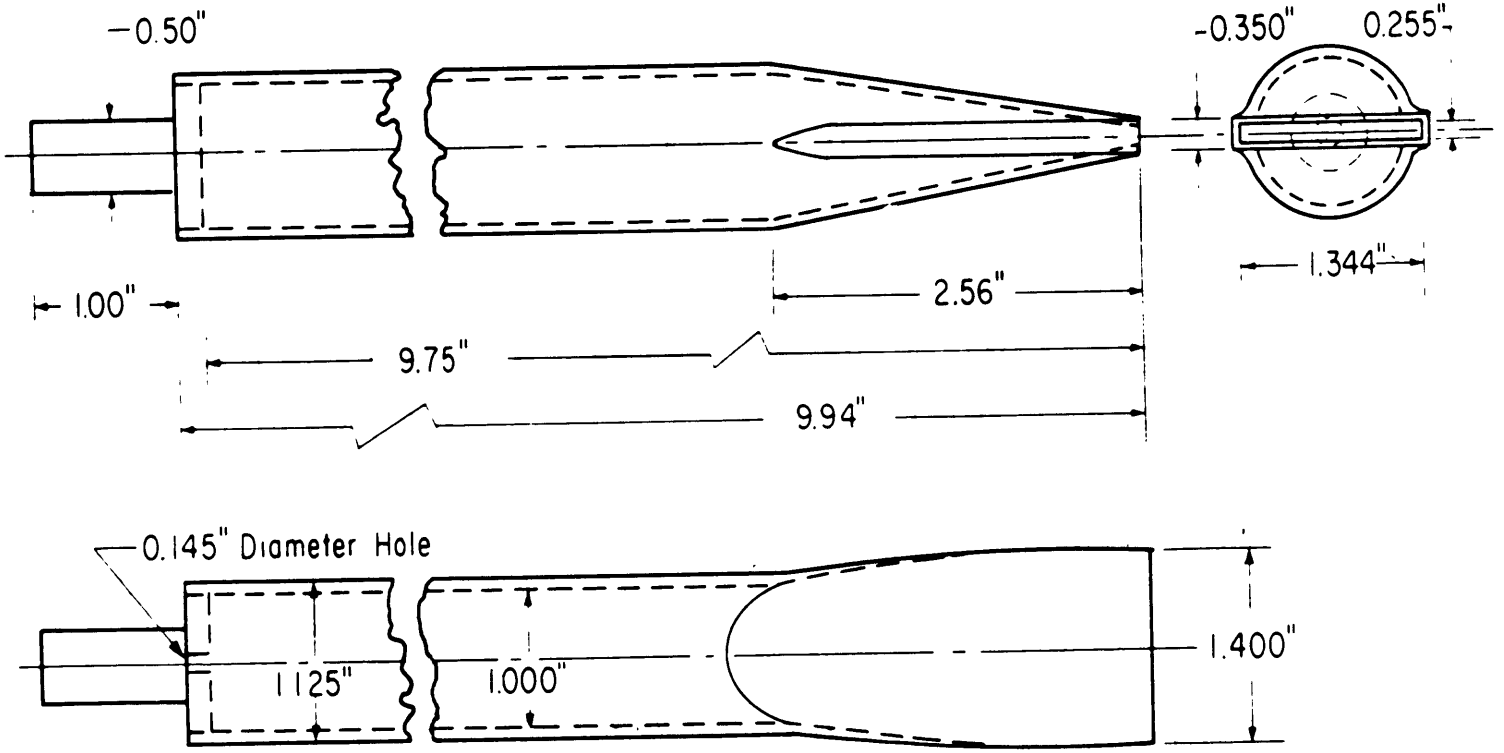


Figure 3 - Sketch of Typical Nozzles

FIGURE 3

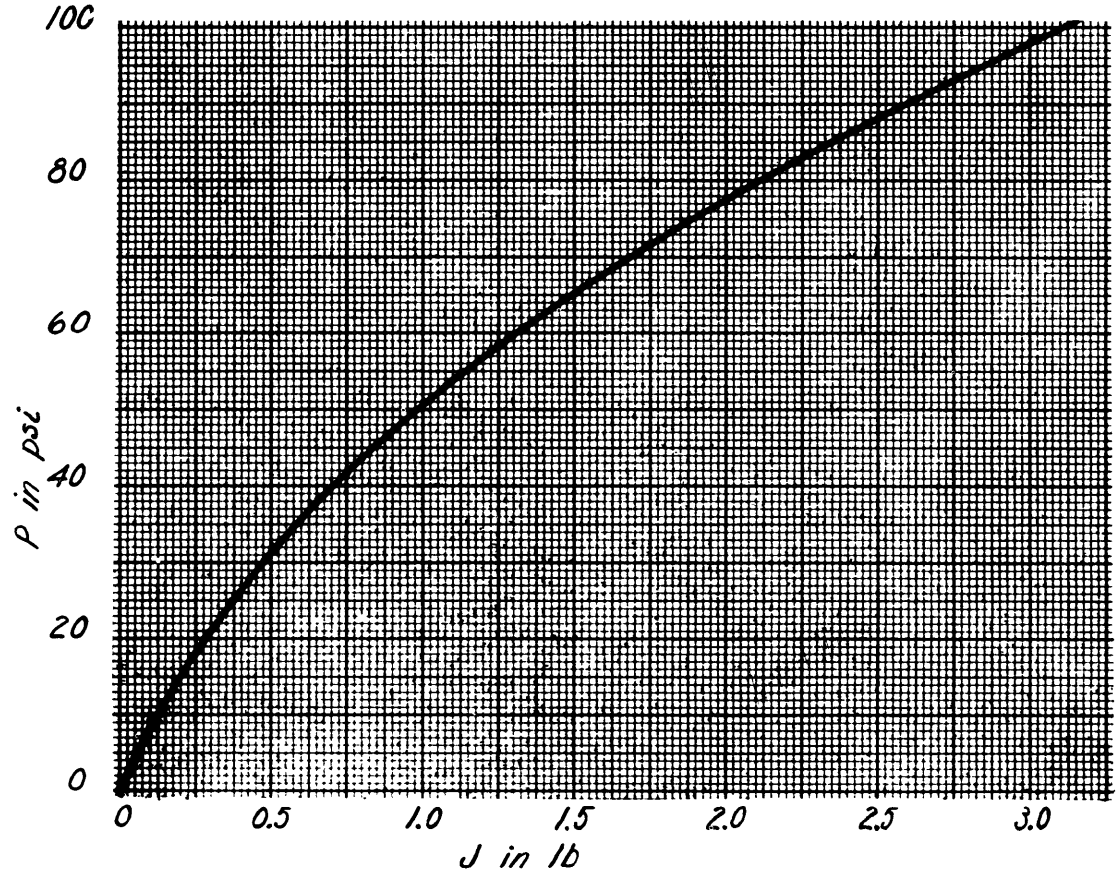


Figure 4 - Nozzle Calibration Curve

FIGURE 4

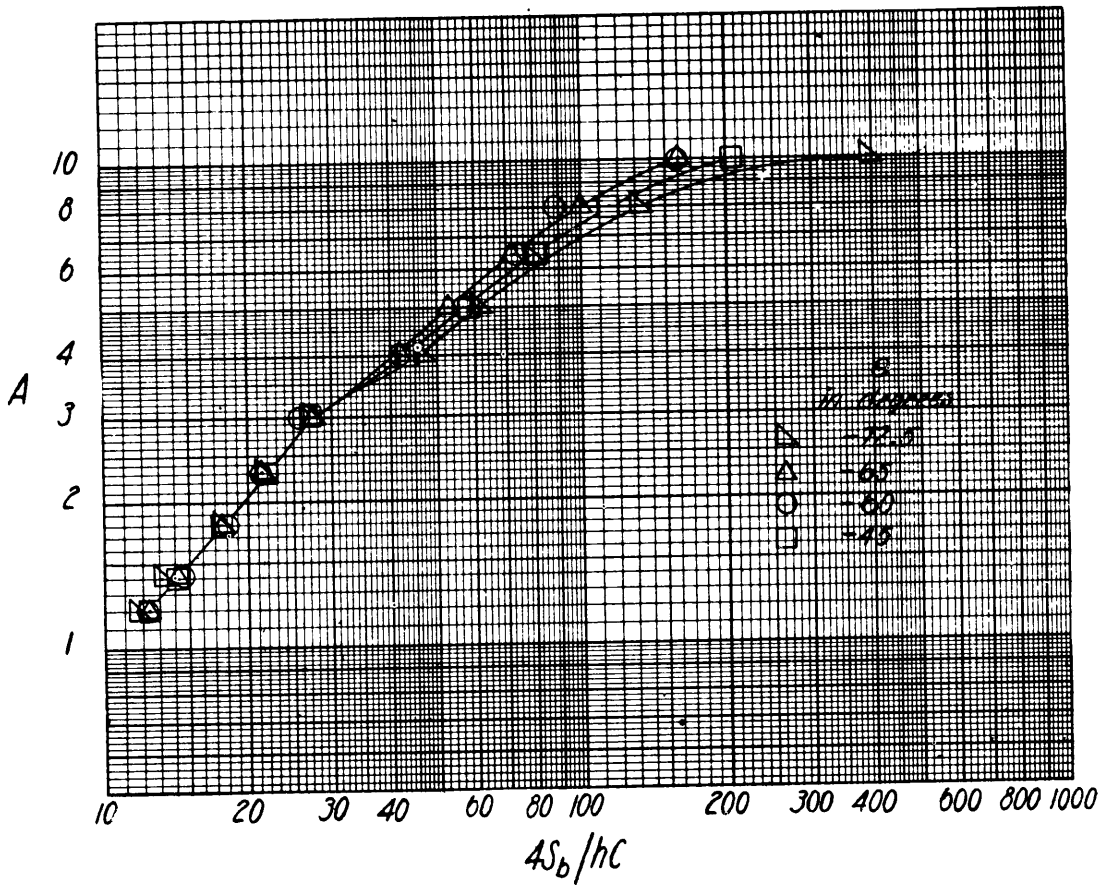


Figure 5 - Variation of Augmentation With Ground Proximity Parameter for an Aspect Ratio of 1

(a) $\frac{f}{c} = 0.1$; $\delta_f = 30^\circ$

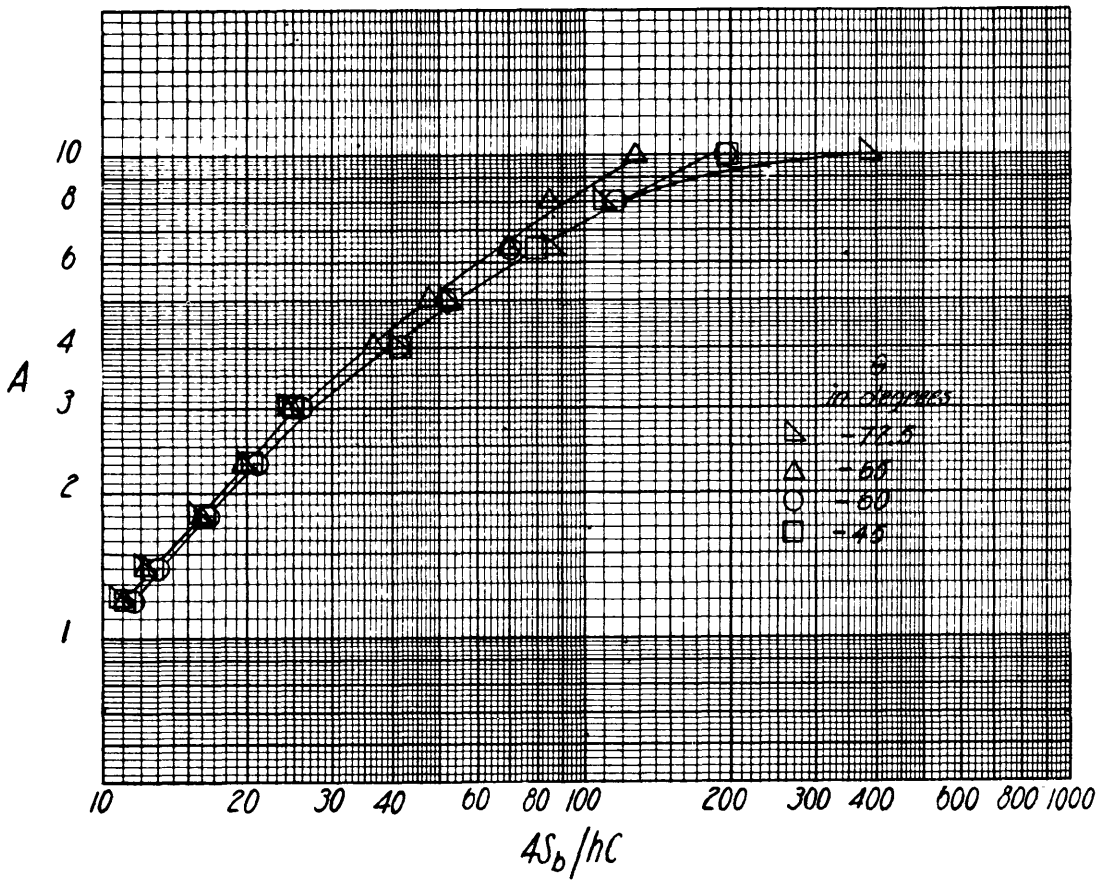


Figure 5 (Continued)

(b) $\frac{f}{c} = 0.1$; $\delta_f = 45^\circ$

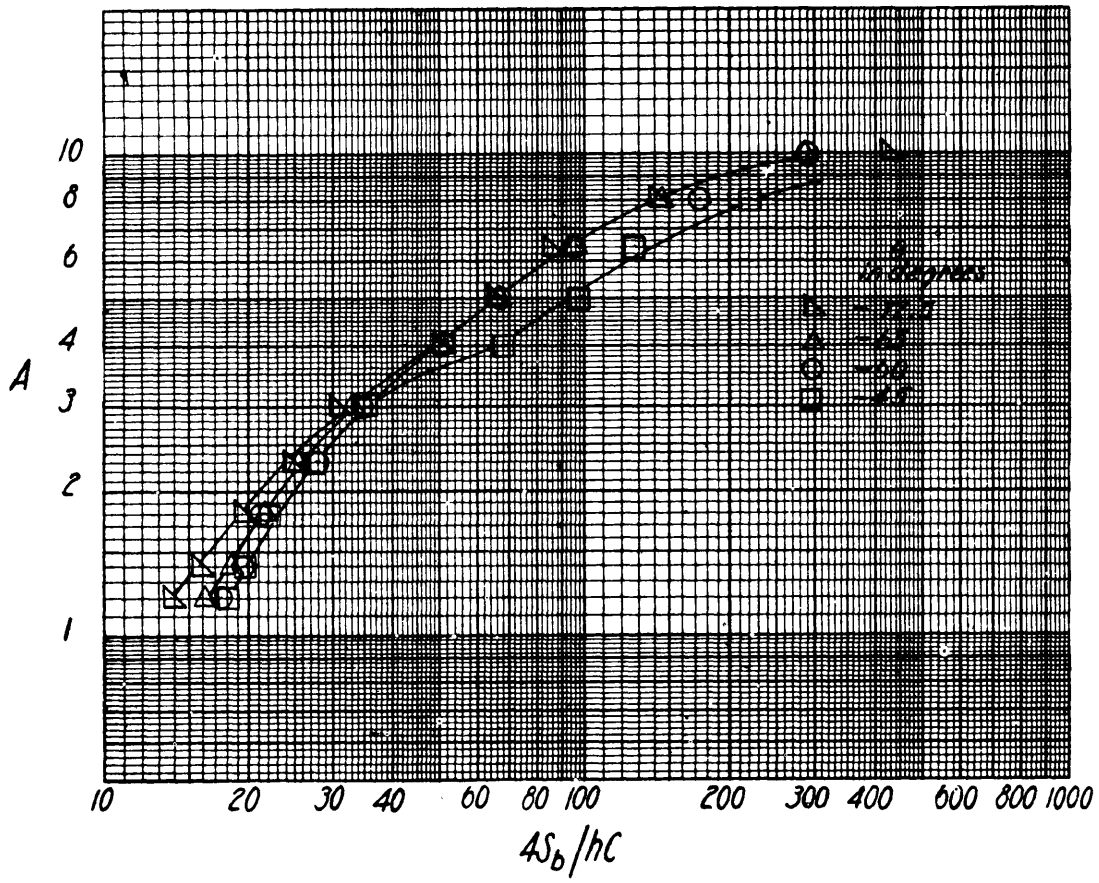


Figure 5 (Continued)

(c) $\frac{f}{c} = 0.2$; $\delta_f = 15^\circ$

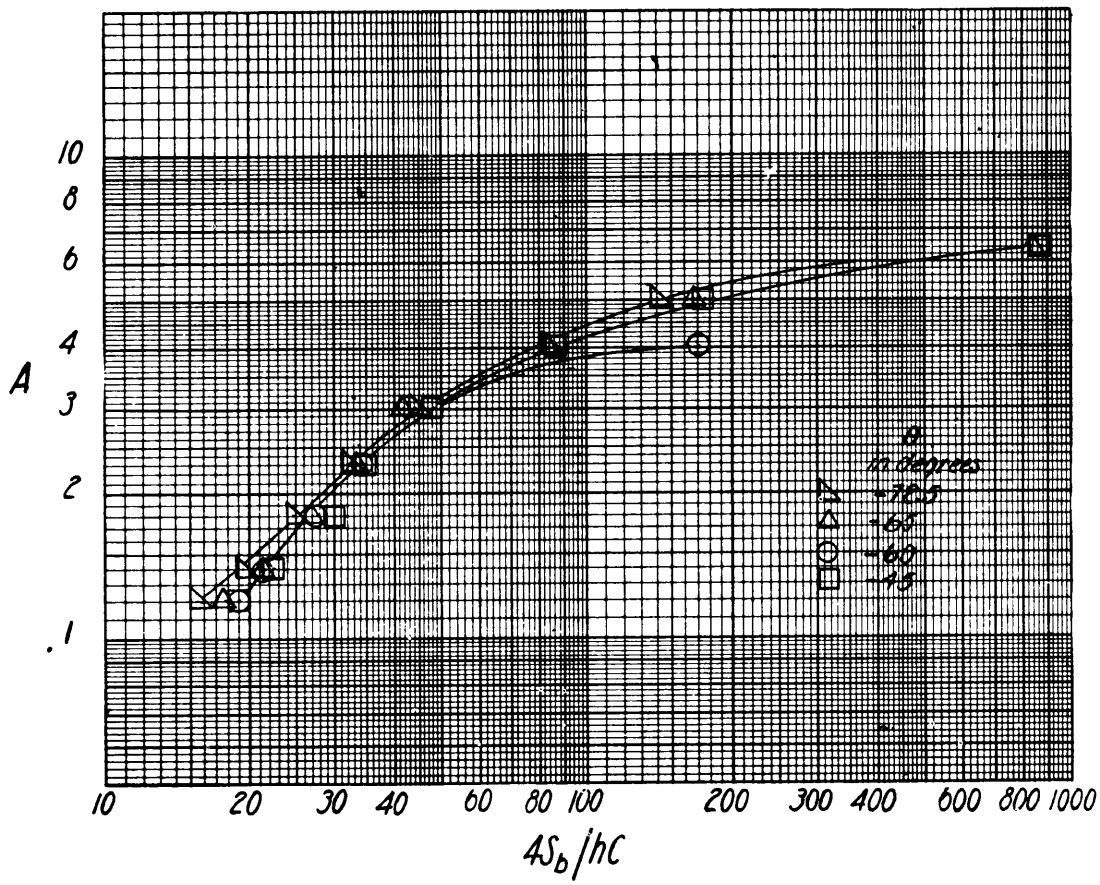


Figure 5 (Continued)

(d) $\frac{f}{c} = 0.2$; $\delta_f = 30^\circ$

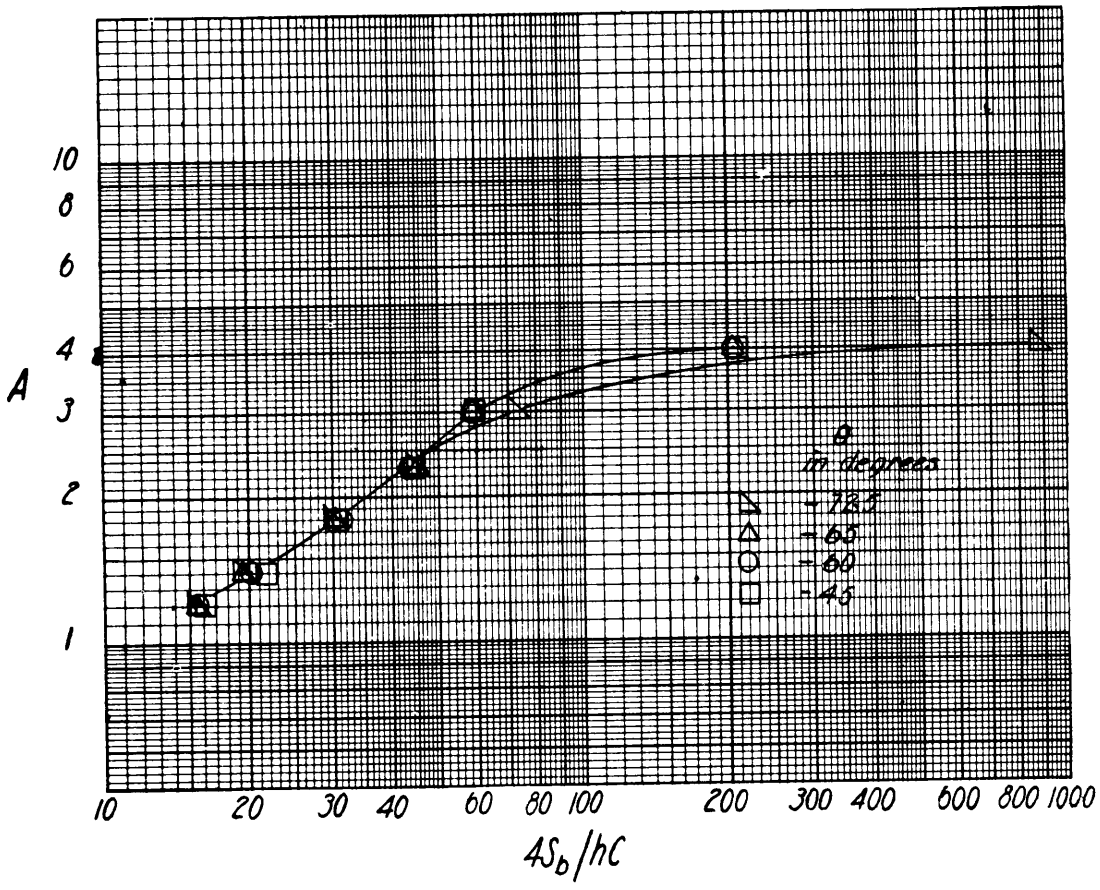


Figure 5 (Continued)

(e) $\frac{f}{c} = 0.2$; $\delta_f = 45^\circ$

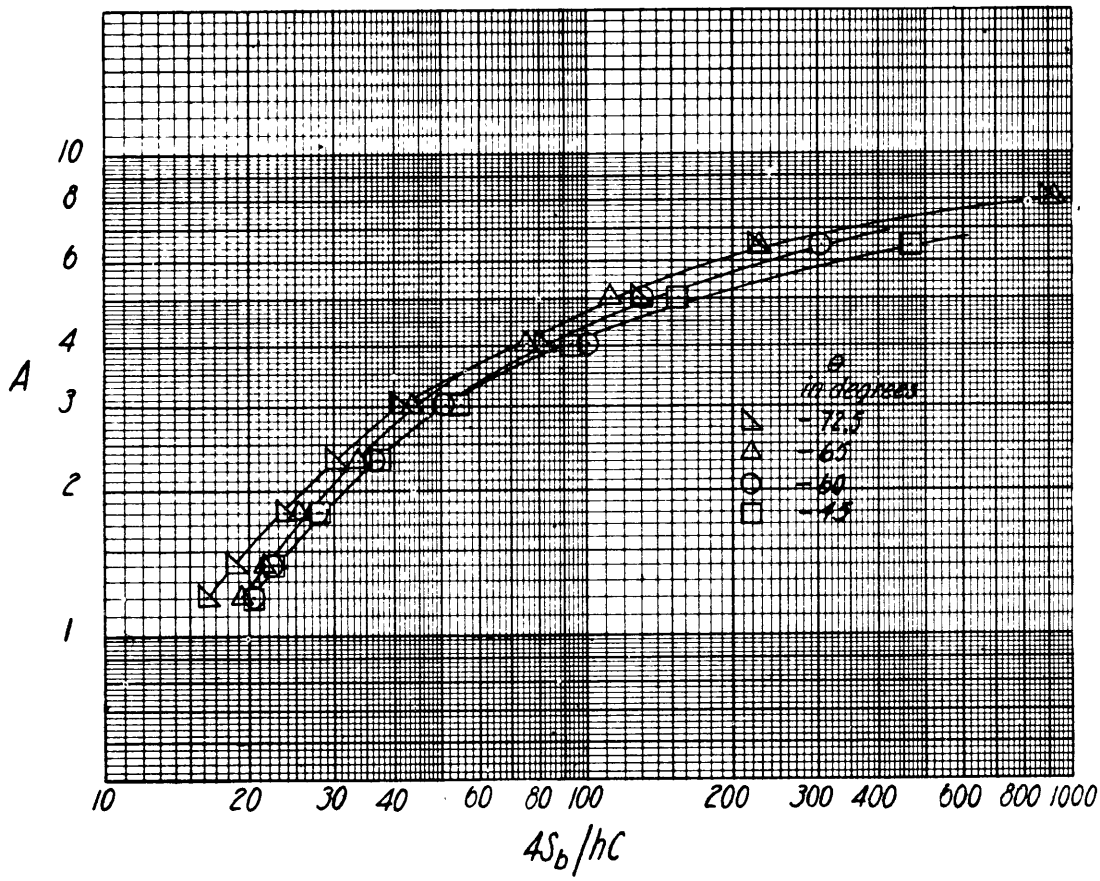


Figure 5 (Continued)

(f) $\frac{f}{c} = 0.3$; $\delta_f = 15^\circ$

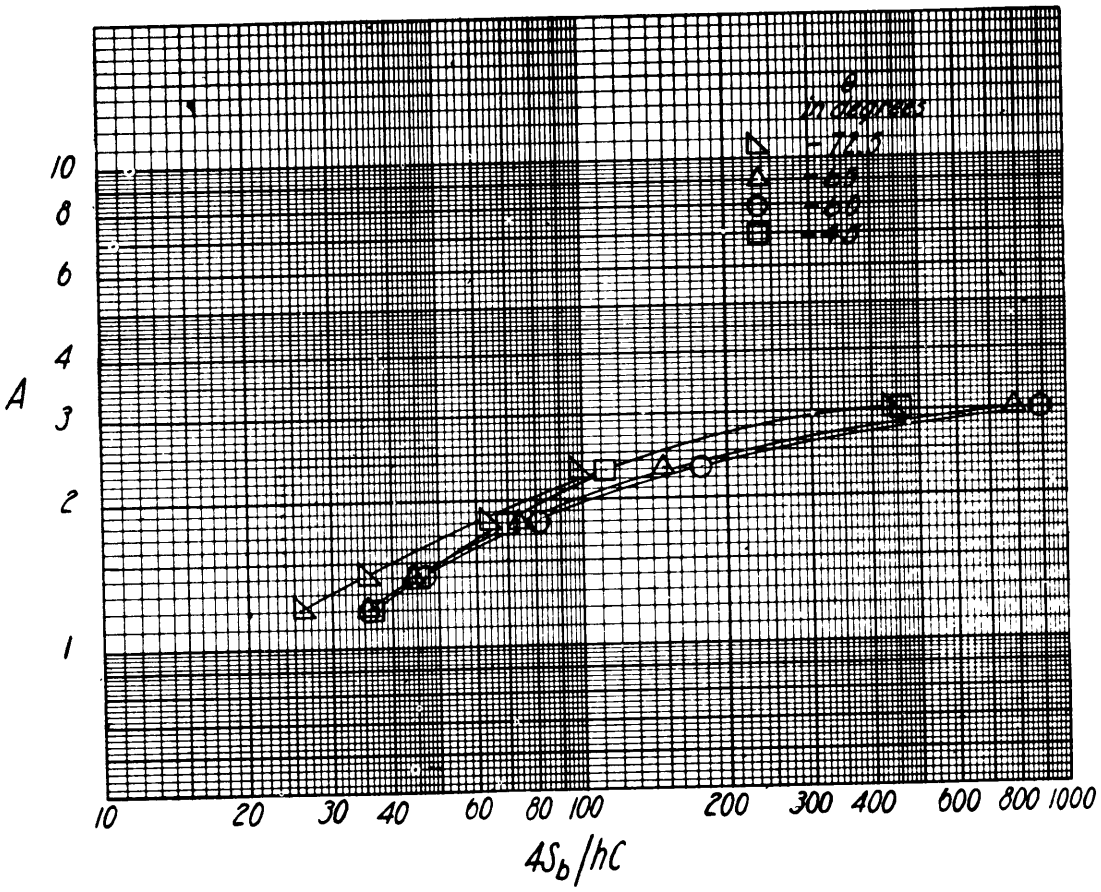
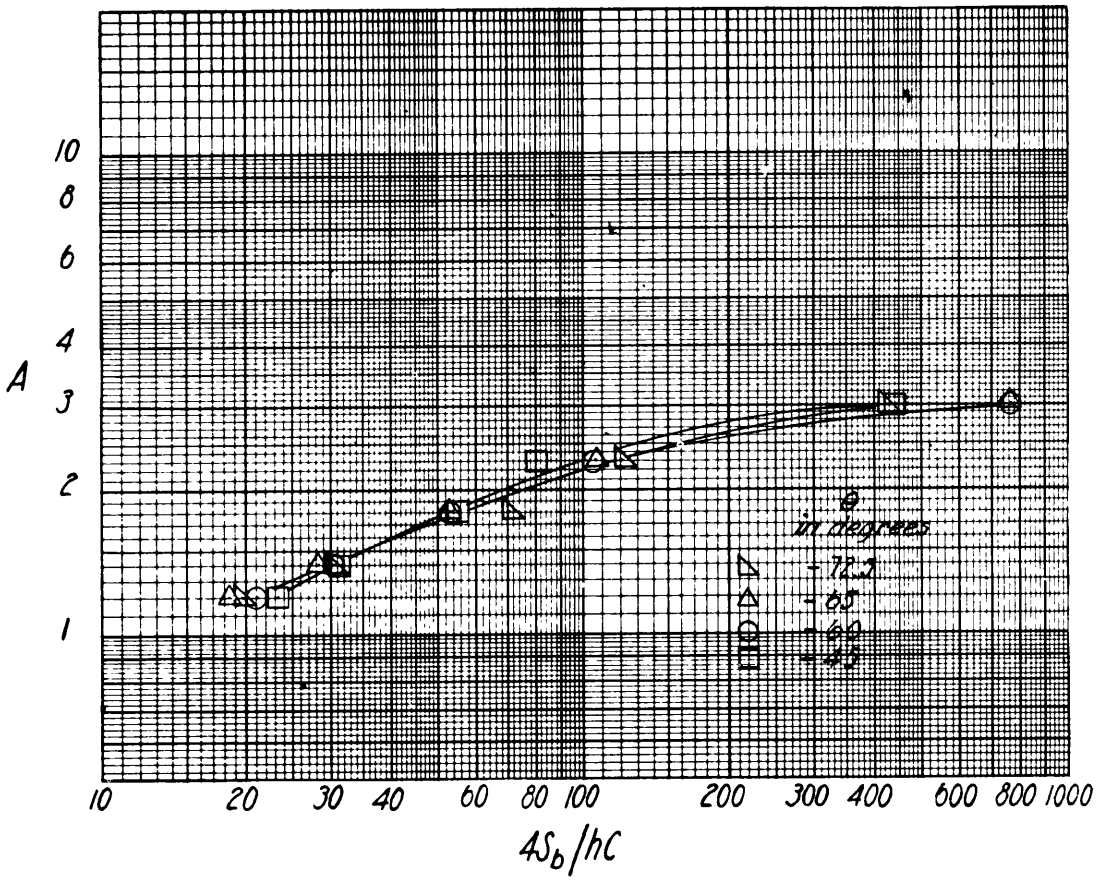


Figure 5 (Continued)

(g) $\frac{f}{c} = 0.3$; $\delta_f = 30^\circ$



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(h) $\frac{f}{c} = 0.3$; $\delta_f = 45^\circ$

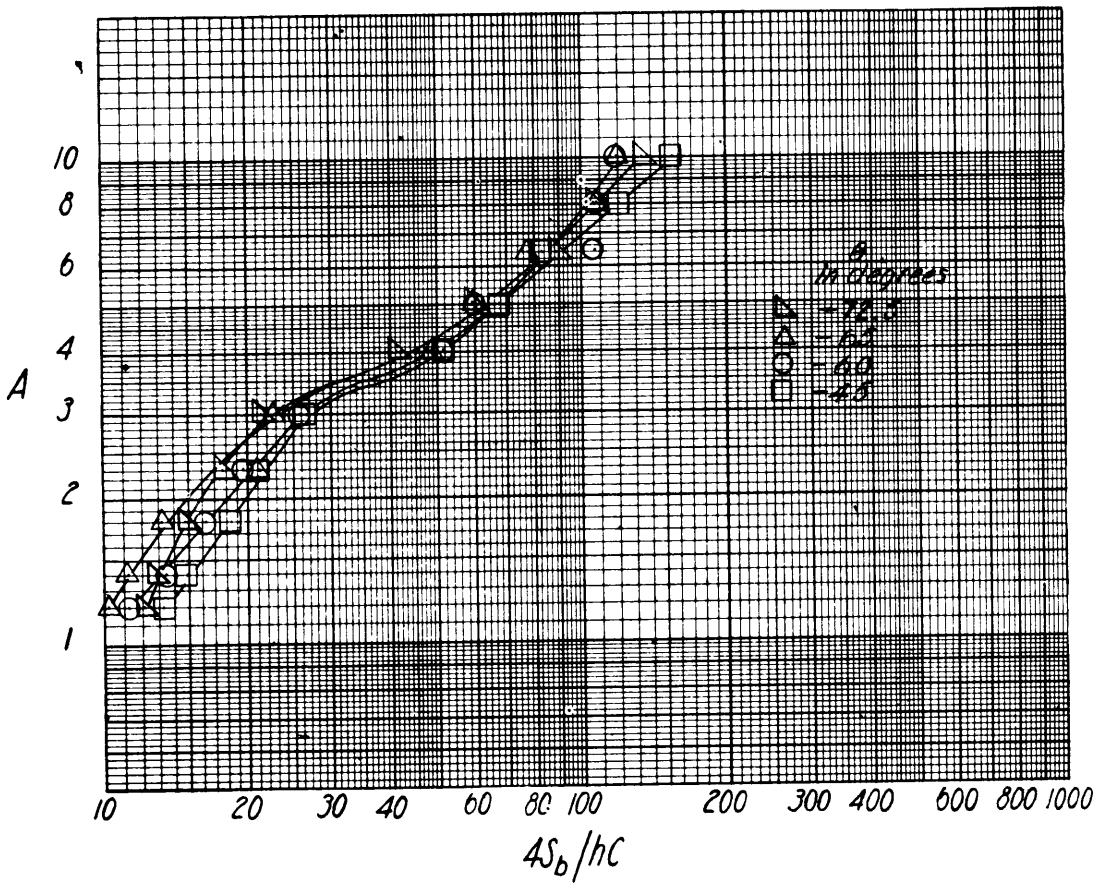
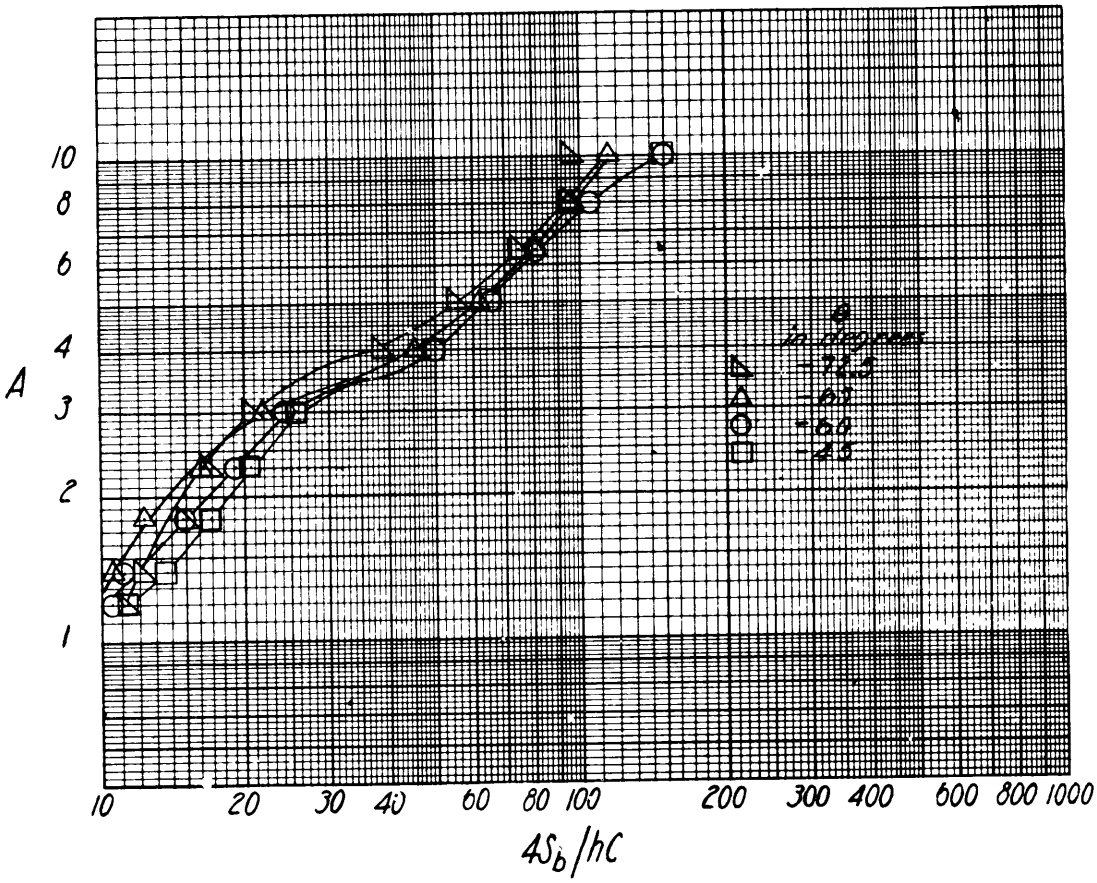


Figure 6 - Variation of Augmentation With Ground Proximity Parameter for an Aspect Ration of 2

(a) $\frac{f}{c} = 0.1$; $\delta_f = 30^\circ$



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(b) $\frac{f}{c} = 0.1$; $\delta_f = 45^\circ$

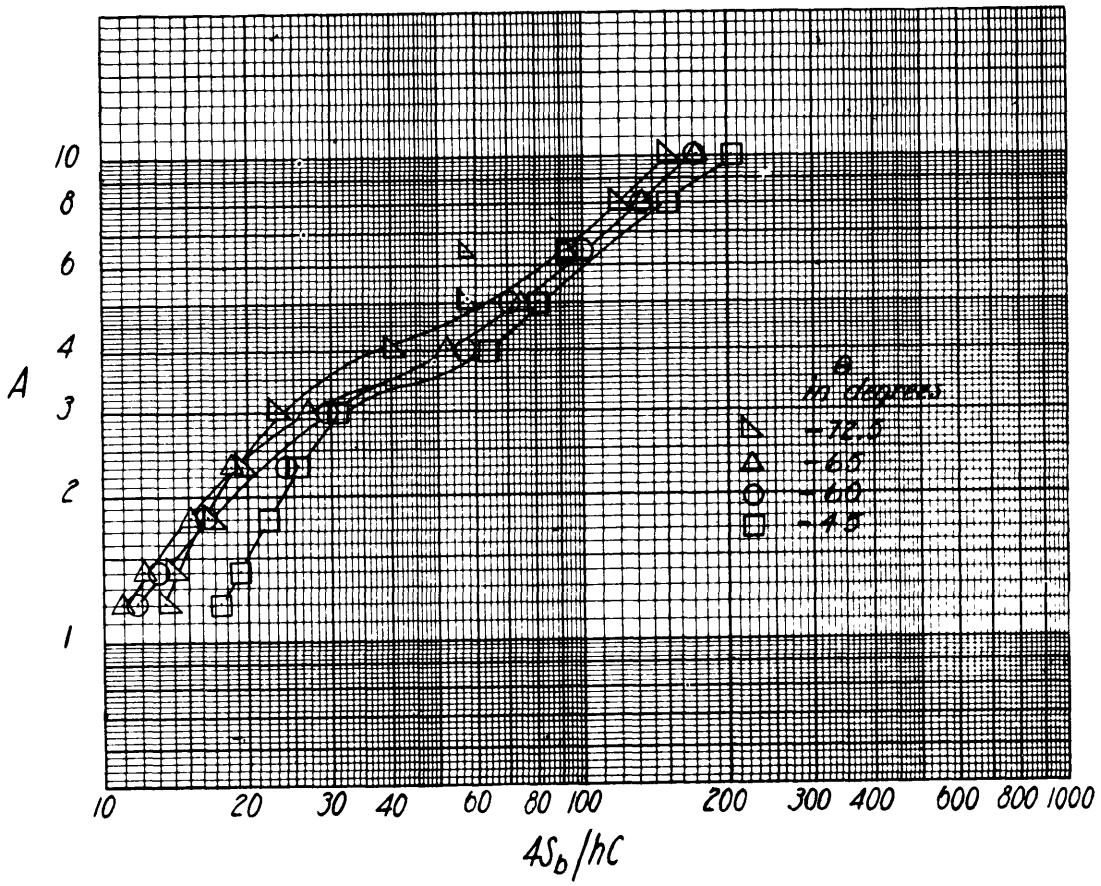
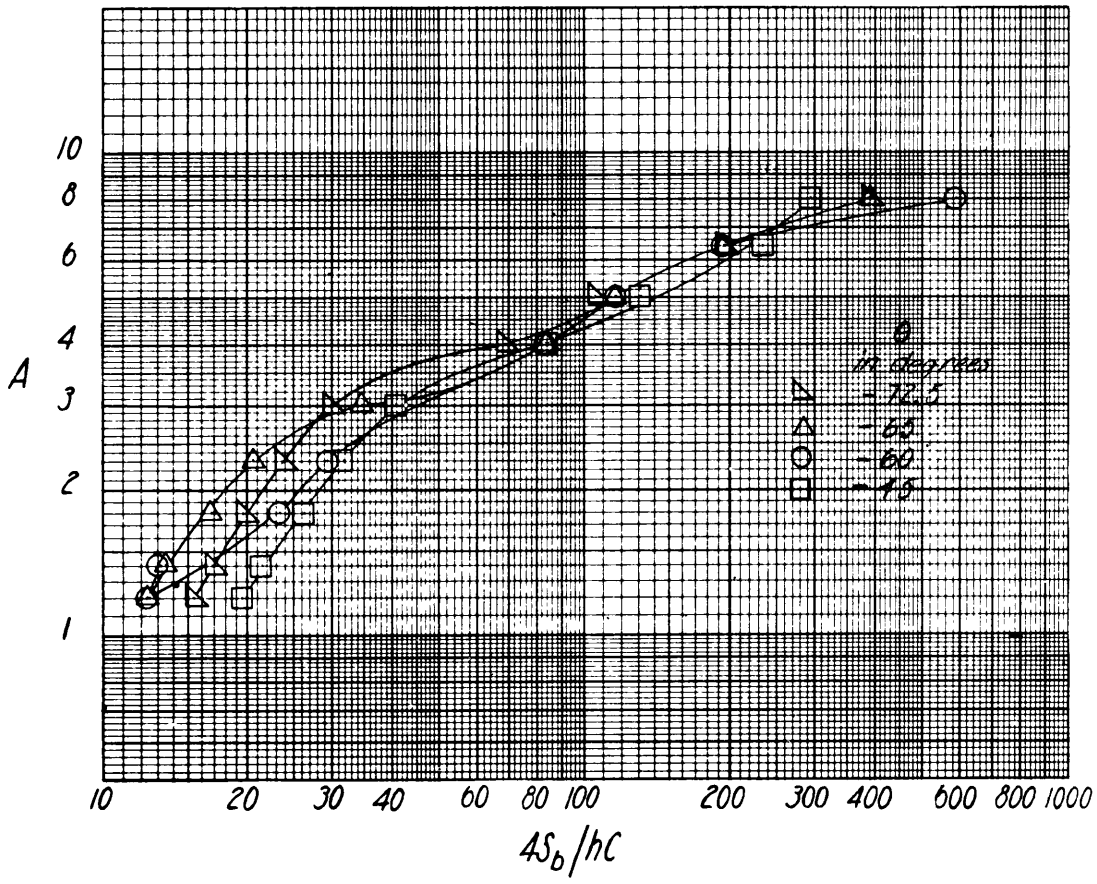


Figure 6 (Continued)

(c) $\frac{f}{c} = 0.2$; $\delta_f = 15^\circ$



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(d) $\frac{f}{c} = 0.2$; $\delta_f = 30^\circ$

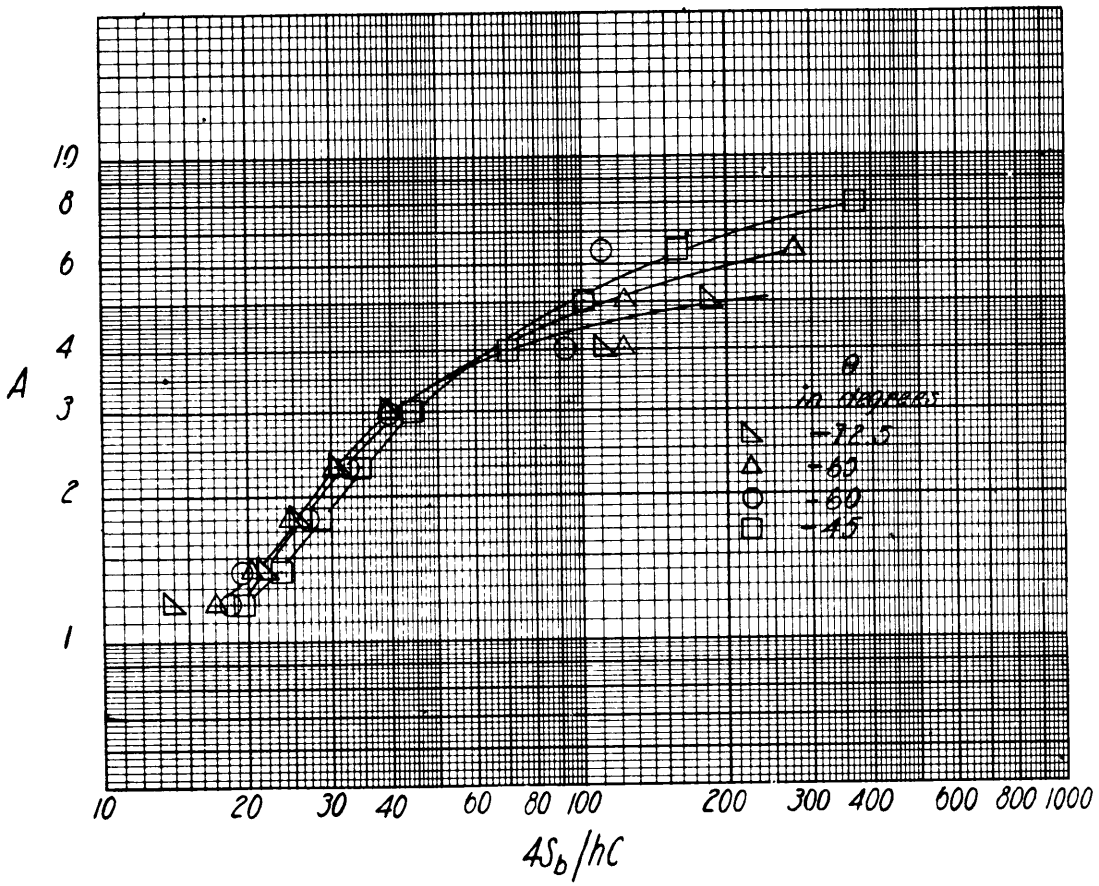

Figure 6 (Continued)

(e) $\frac{f}{c} = 0.2$; $\delta_f = 45^\circ$

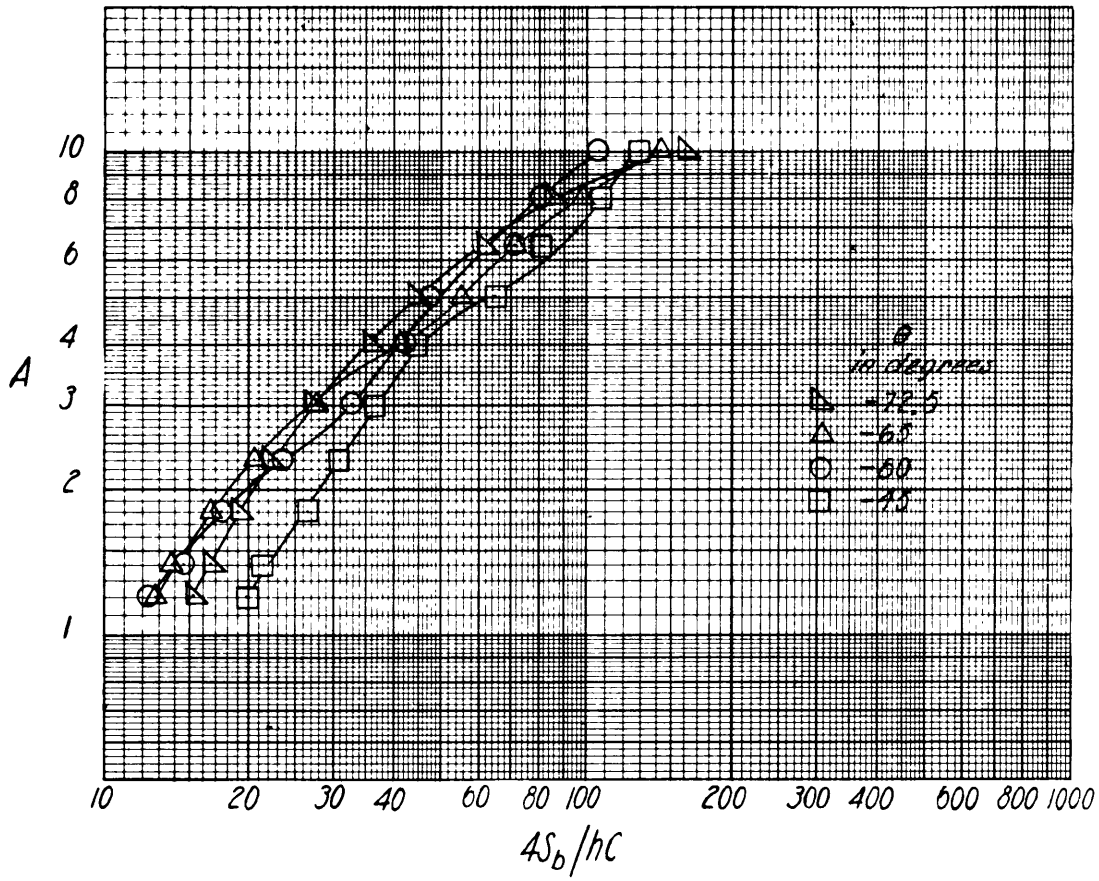

Figure 6 (Continued)

(f) $\frac{f}{c} = 0.3$; $\delta_f = 15^\circ$

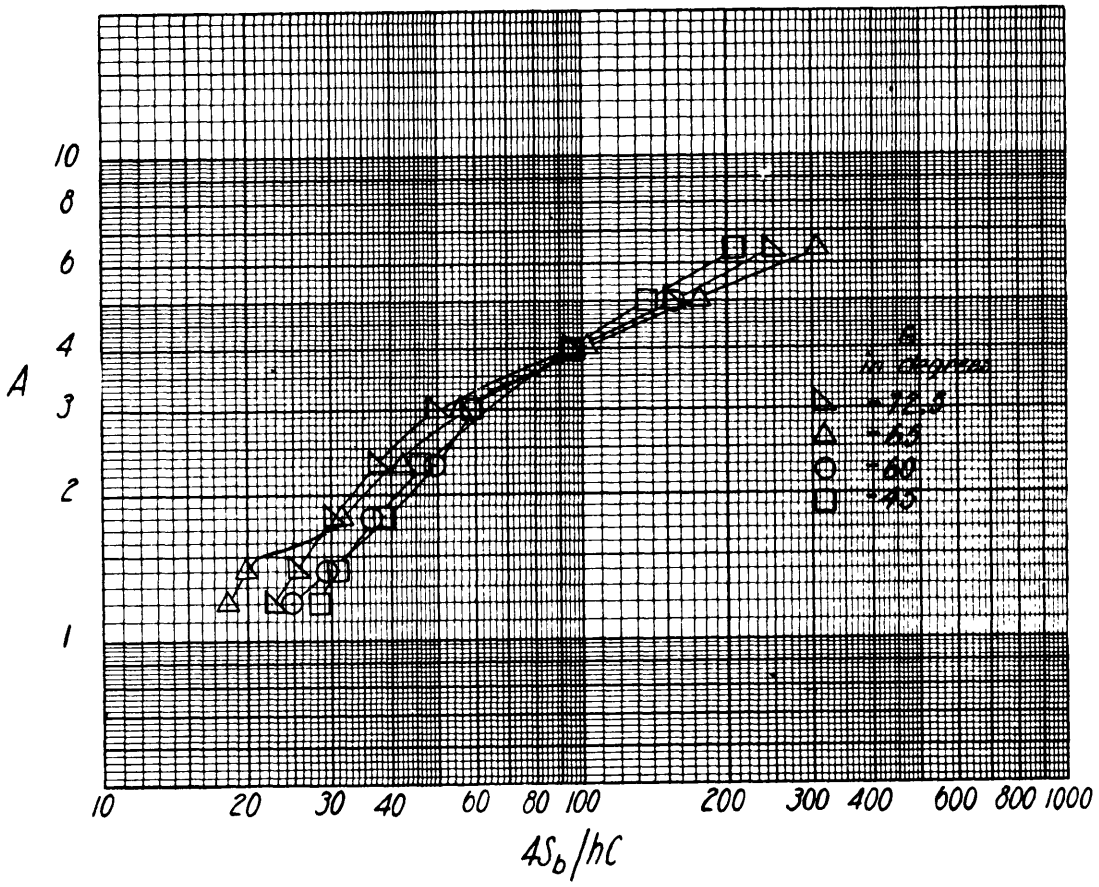

Figure 6 (Continued)

(g) $\frac{f}{c} = 0.3$; $\delta_f = 30^\circ$

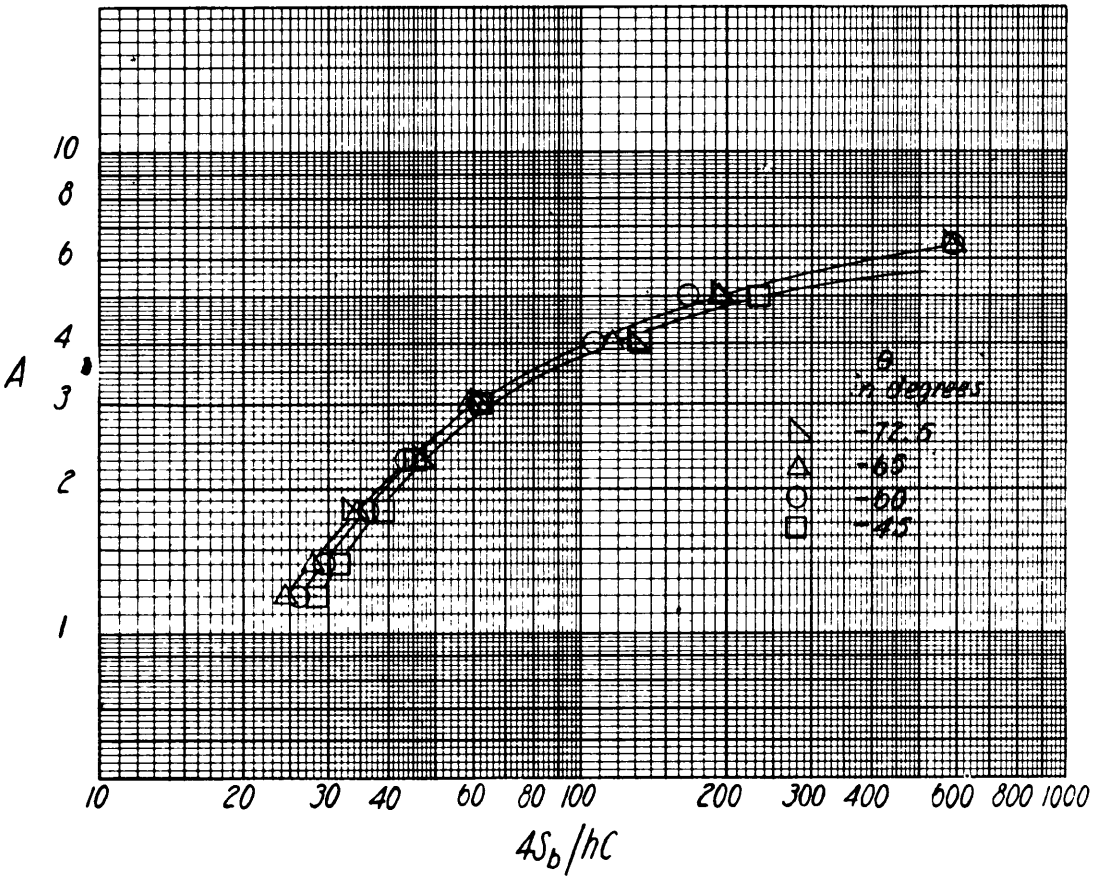

Figure 6 (Concluded)

(h) $\frac{f}{c} = 0.3$; $\delta_f = 45^\circ$

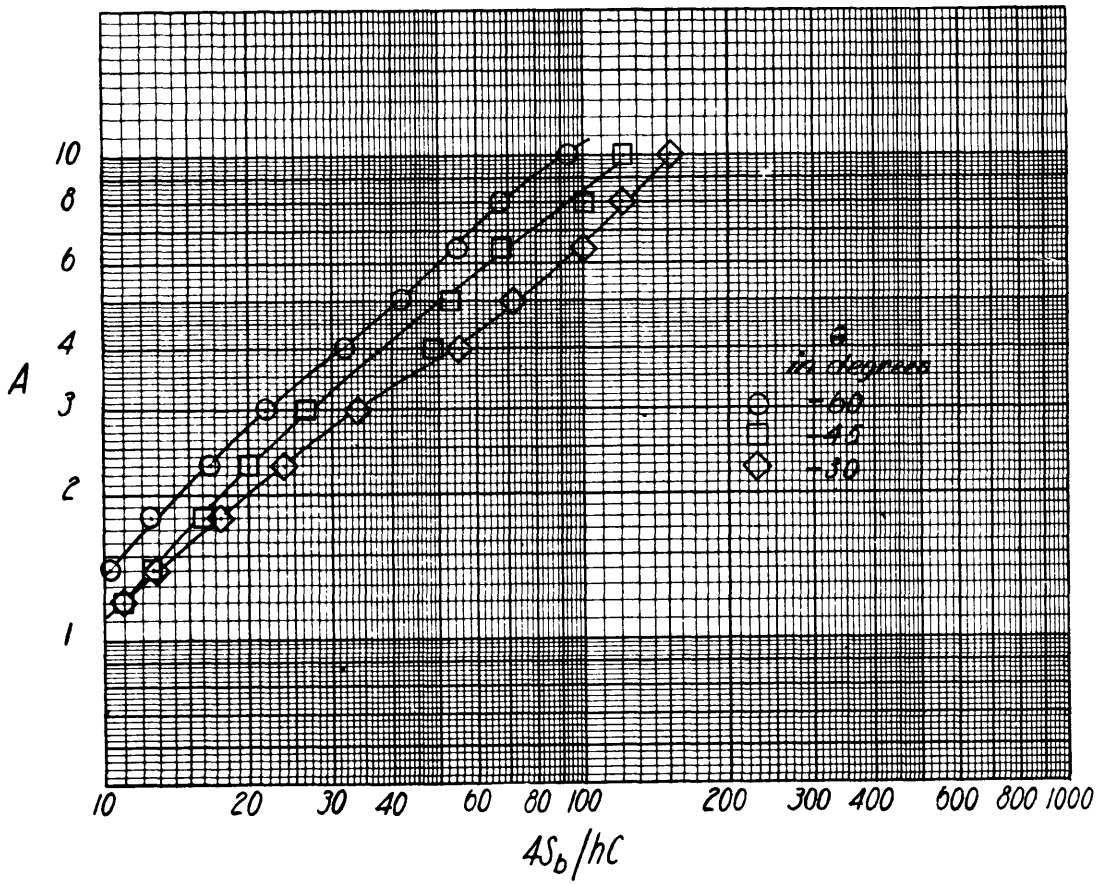

Figure 7 - Variation of Augmentation With Ground Proximity Parameter for an Aspect Ratio of 3

(a) $\frac{f}{c} = 0.1$; $\delta_f = 30^\circ$

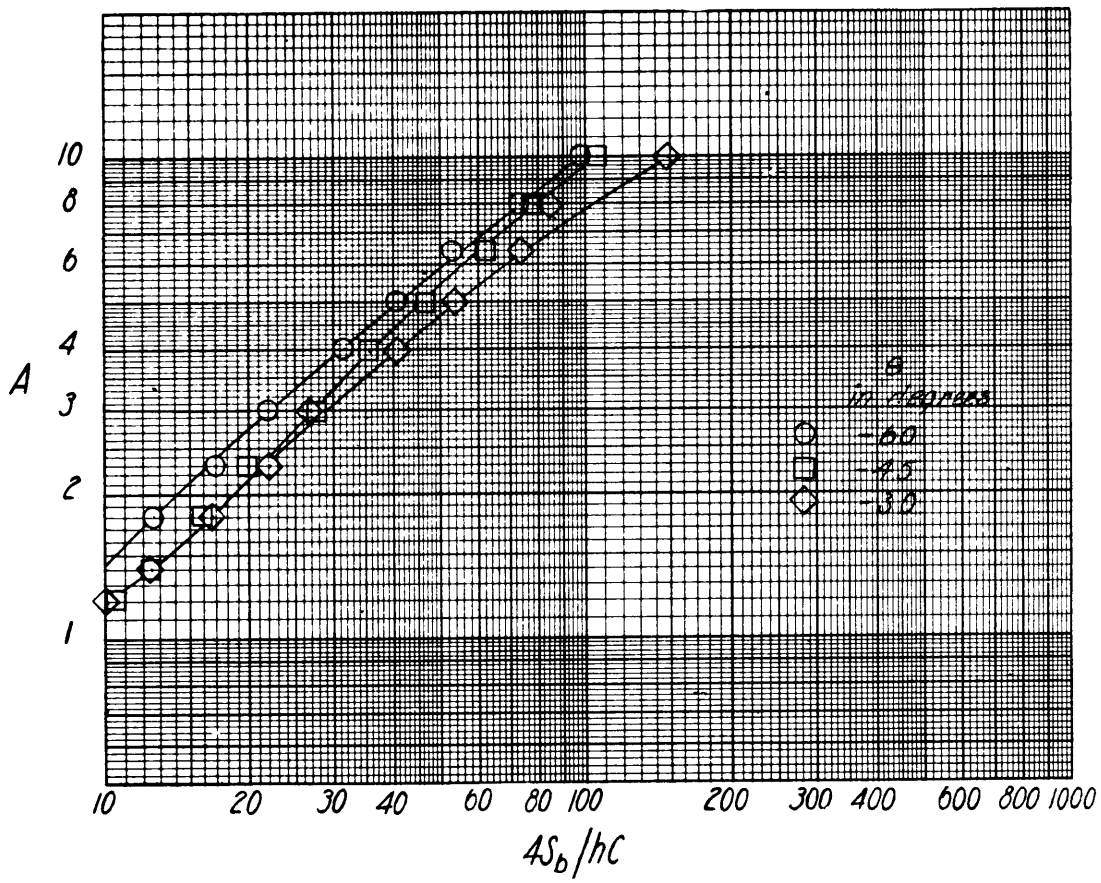

Figure 7 (Continued)

(b) $\frac{f}{c} = 0.1$; $\delta_f = 45^\circ$

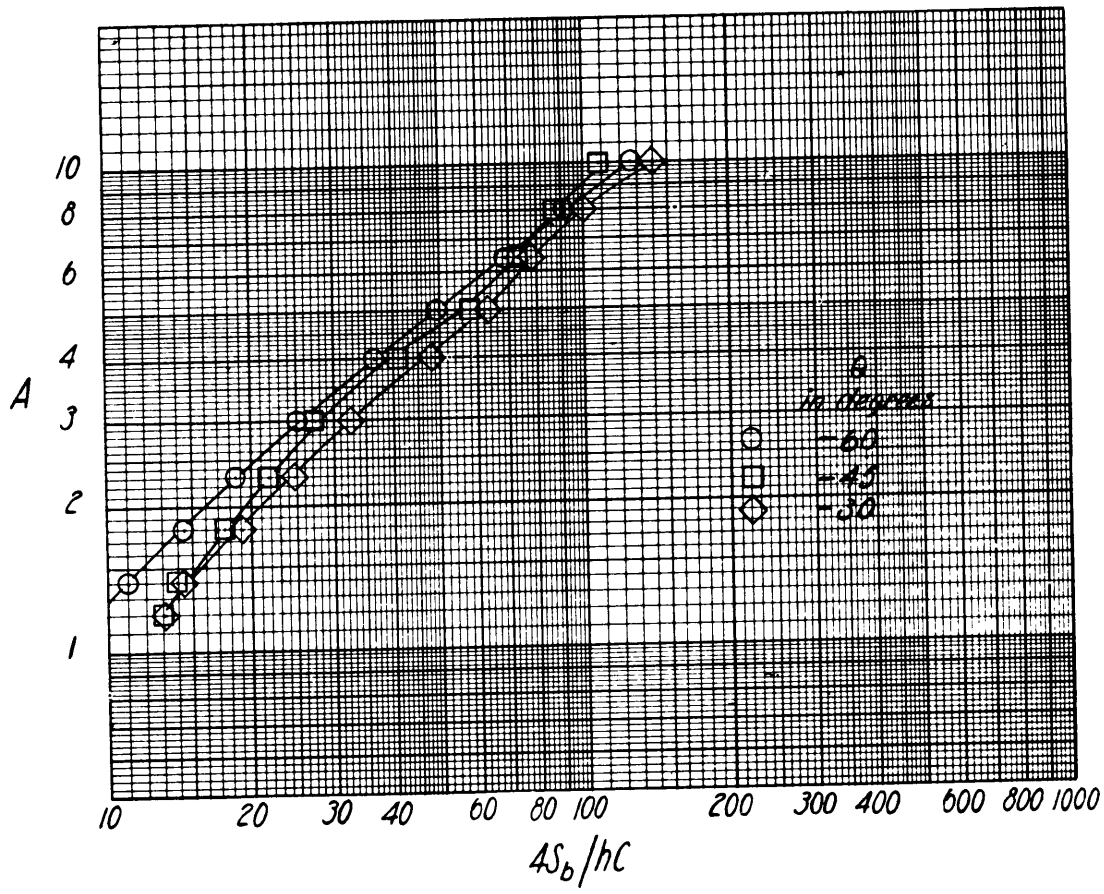

Figure 7 (Continued)

(c) $\frac{f}{c} = 0.2$; $\delta_f = 15^\circ$

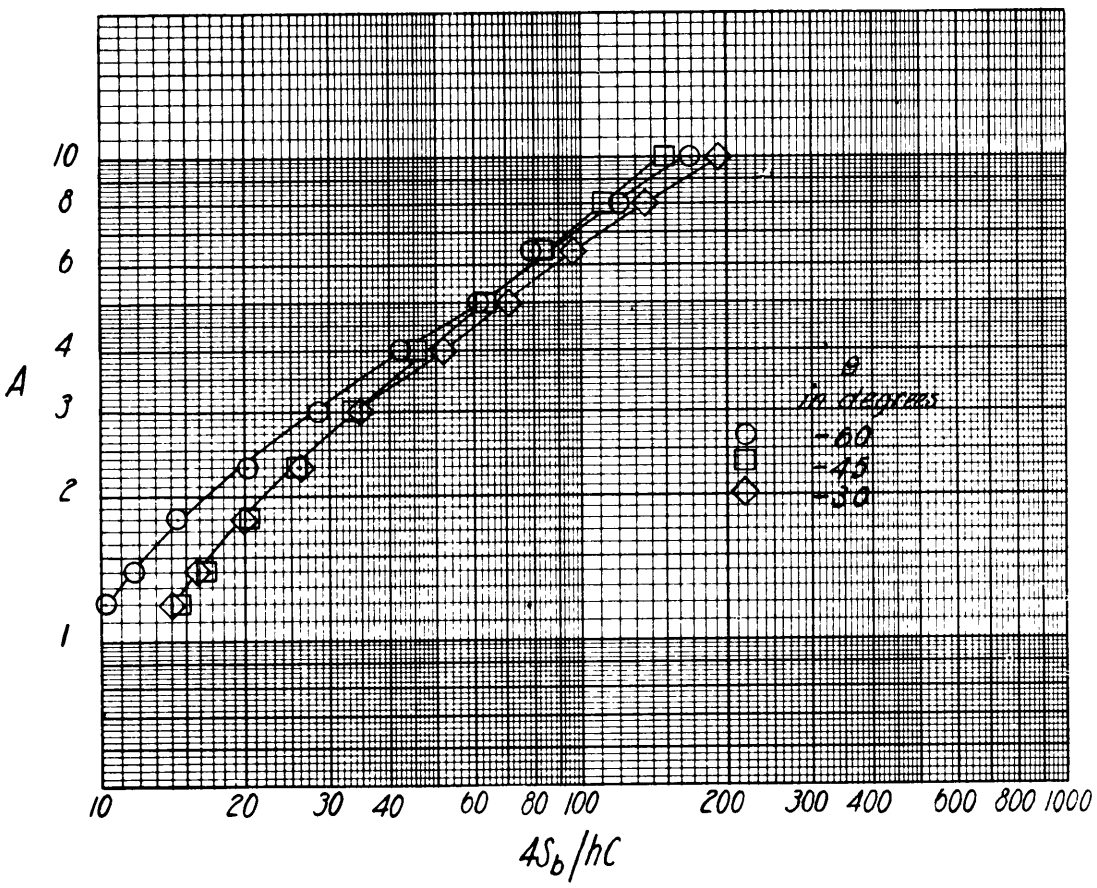

Figure 7 (Continued)

(d) $\frac{f}{c} = 0.2$; $\delta_f = 30^\circ$

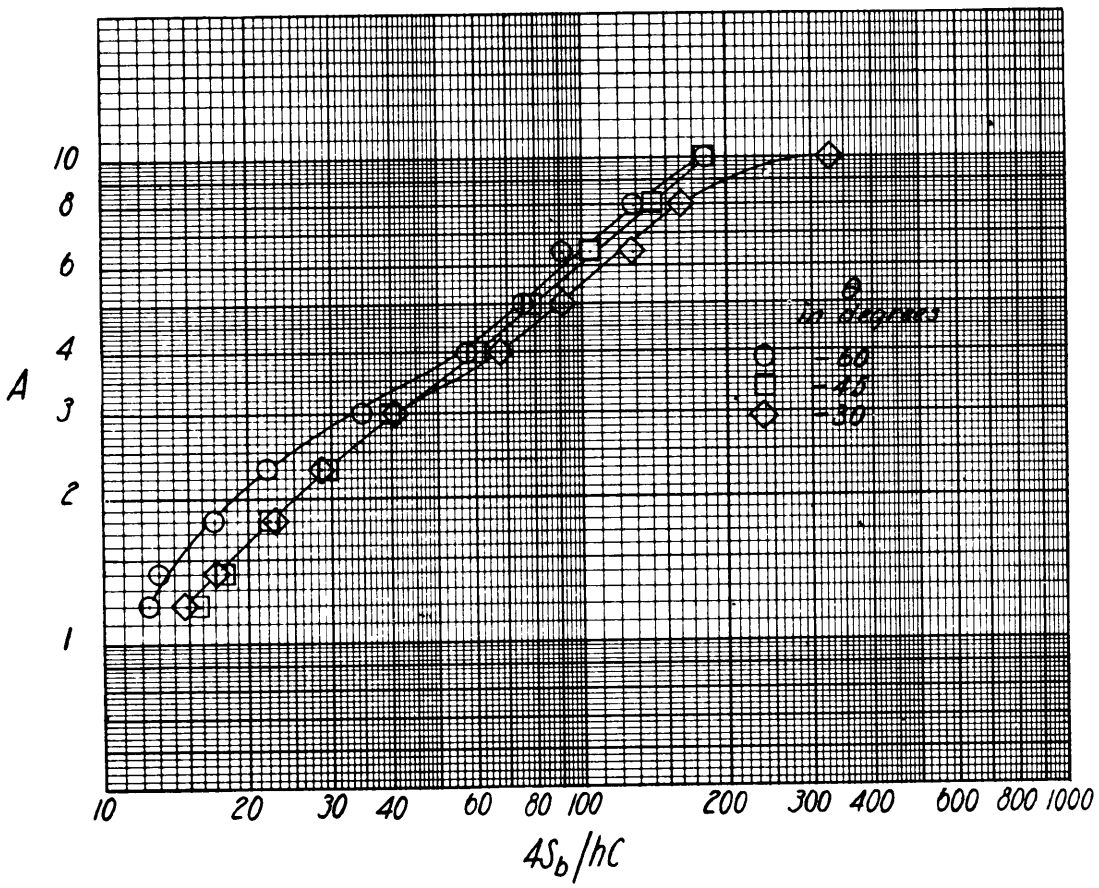

Figure 7 (Continued)

(e) $\frac{f}{c} = 0.2$; $\delta_f = 45^\circ$

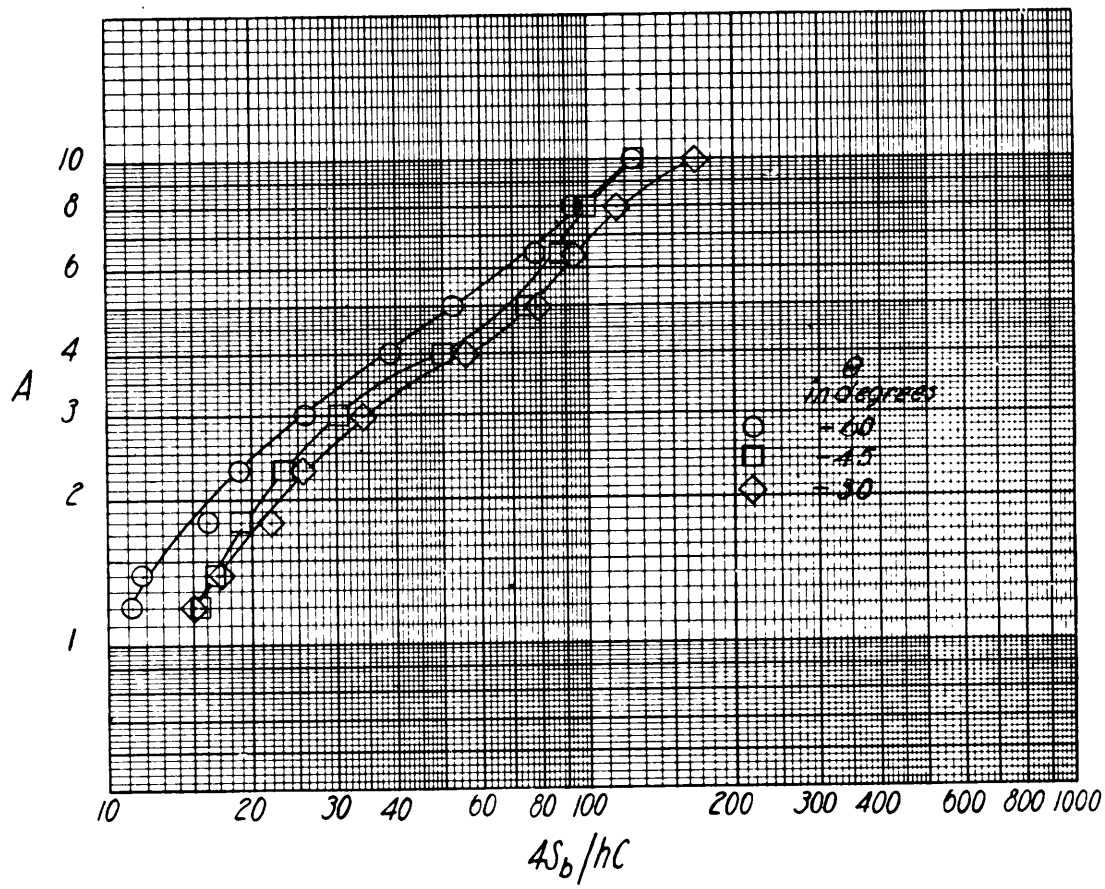

Figure 7 (Continued)

(f) $\frac{f}{c} = 0.3$; $\delta_f = 15^\circ$

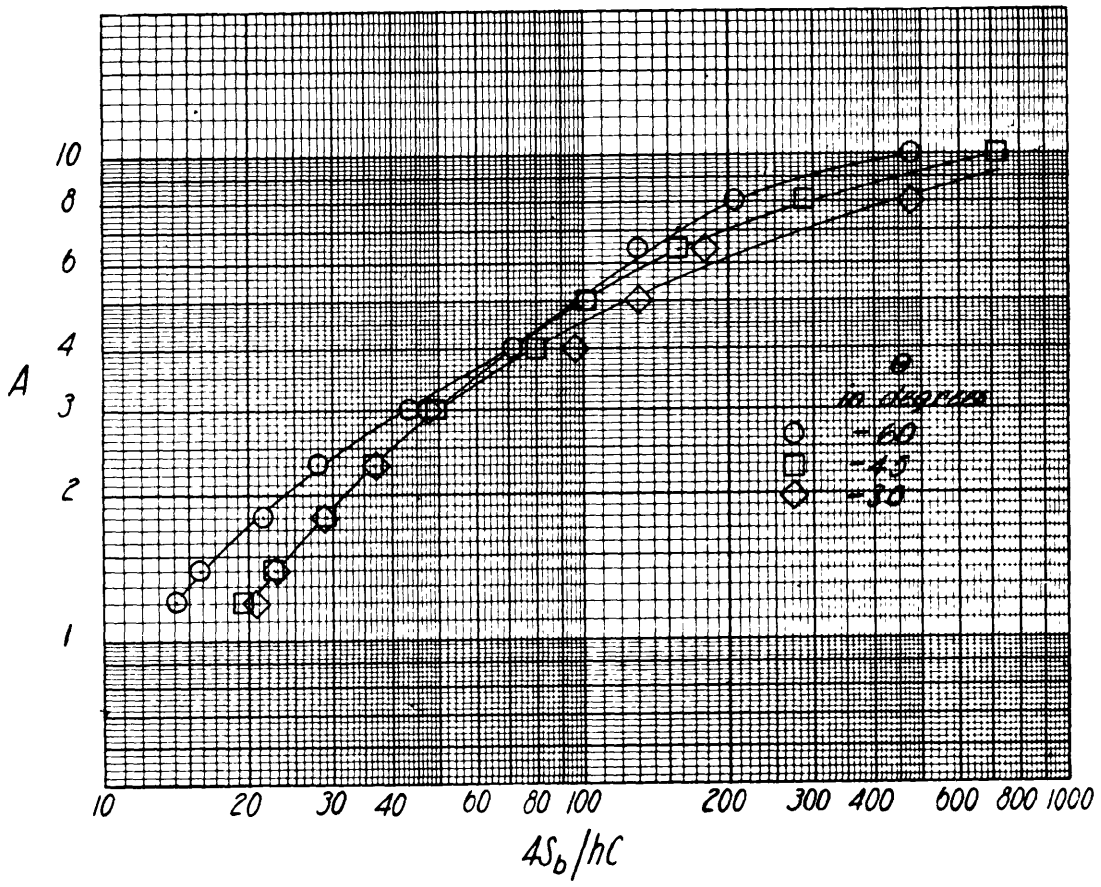

Figure 7 (Continued)

(g) $\frac{f}{c}$ = 0.3; δ_f = 30°

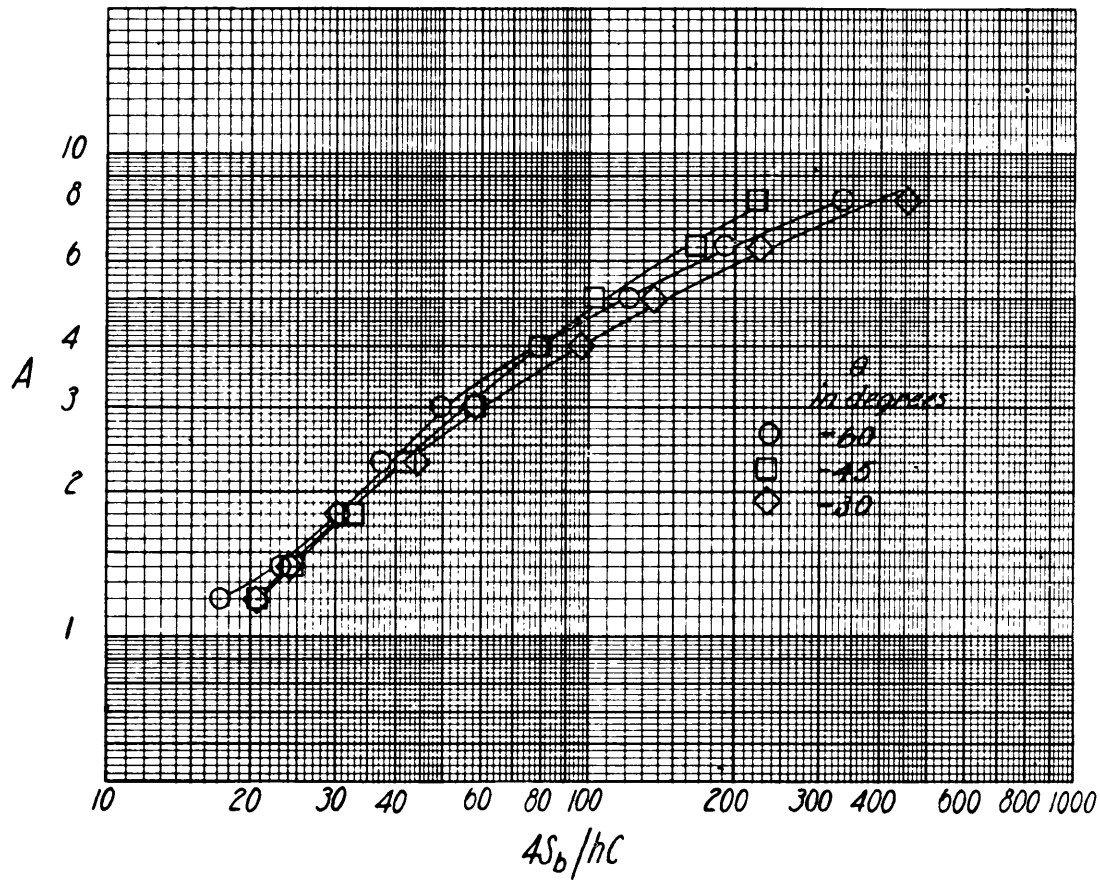

Figure 7 (Concluded)

(h) $\frac{f}{c} = 0.3$; $\delta_f = 45°$

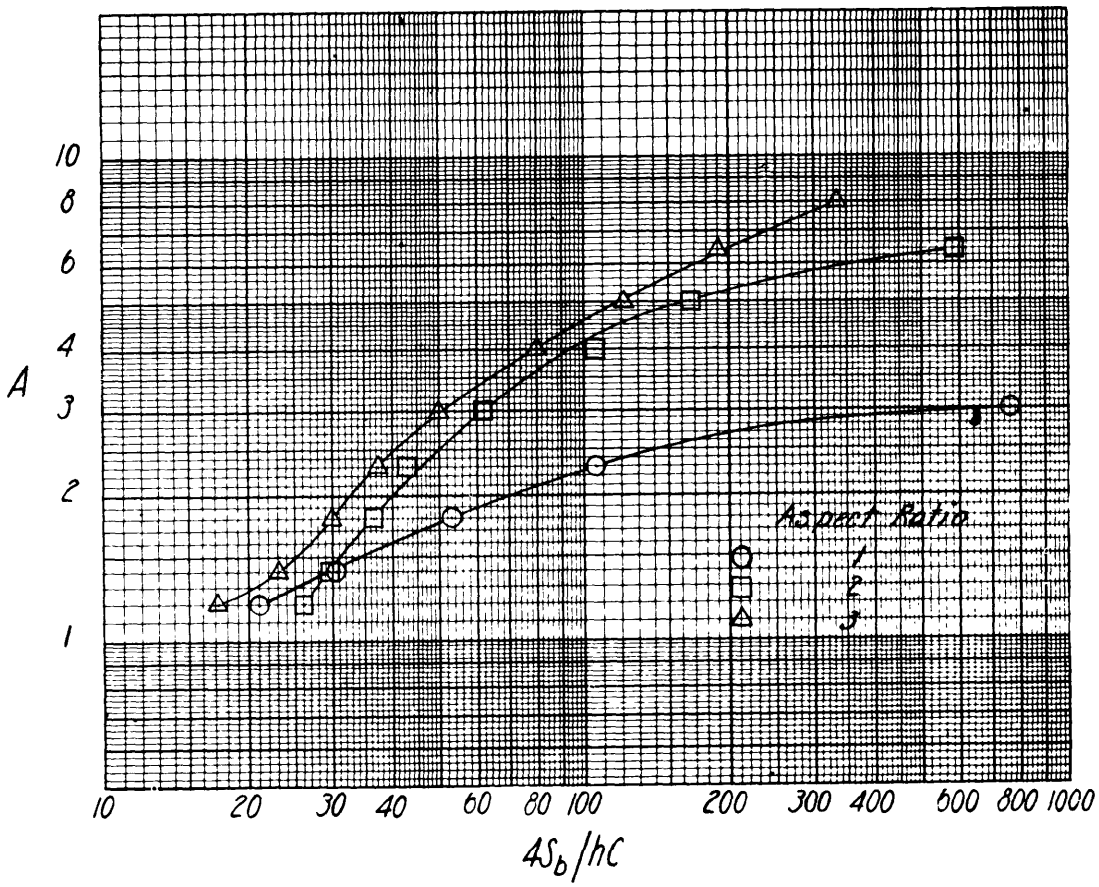

Figure 8 - Variation of Augmentation With Ground Proximity Parameter for Various Values of Aspect Ratio

$\delta_f = 45^\circ$; $\frac{f}{c} = 0.3$; $\theta = -60^\circ$

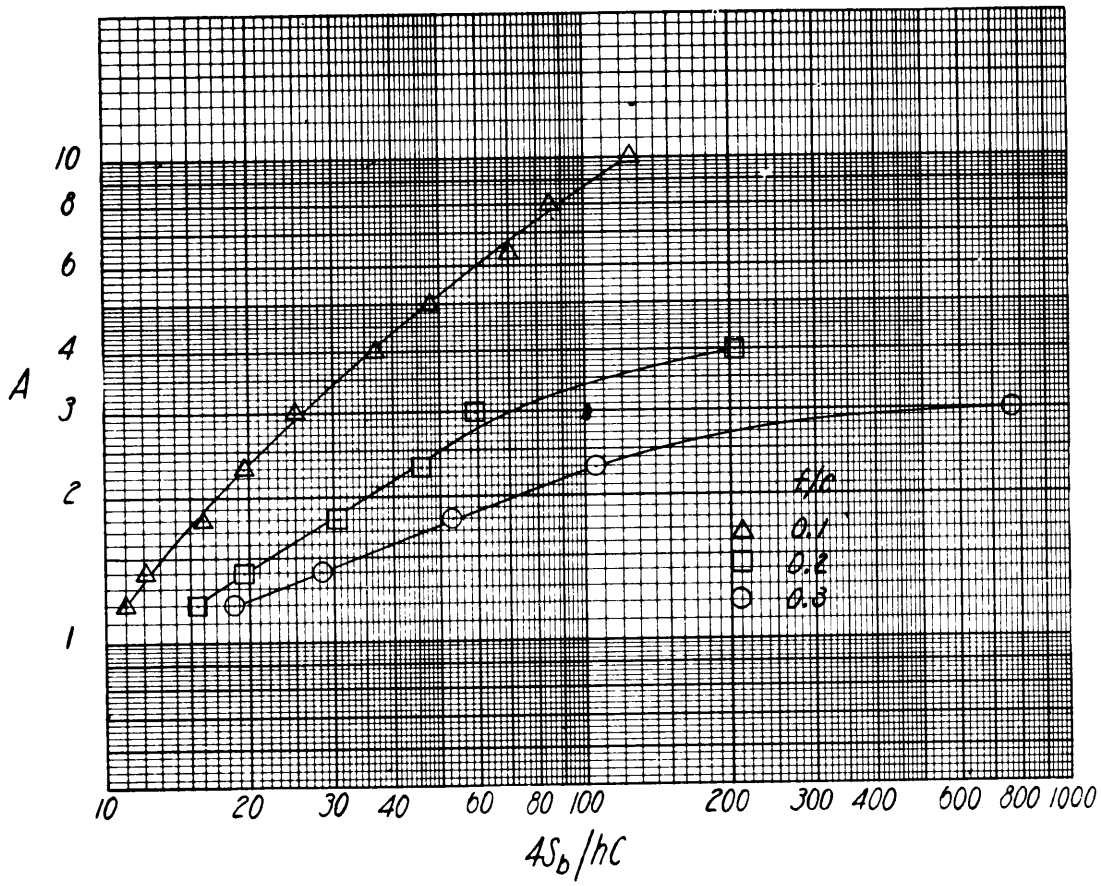

Figure 9 - Variation of Augmentation With Ground Proximity Parameter for Various Values of Flap Chord Length

$\delta_f = 45^\circ$; $\theta = -65^\circ$; AR = 1

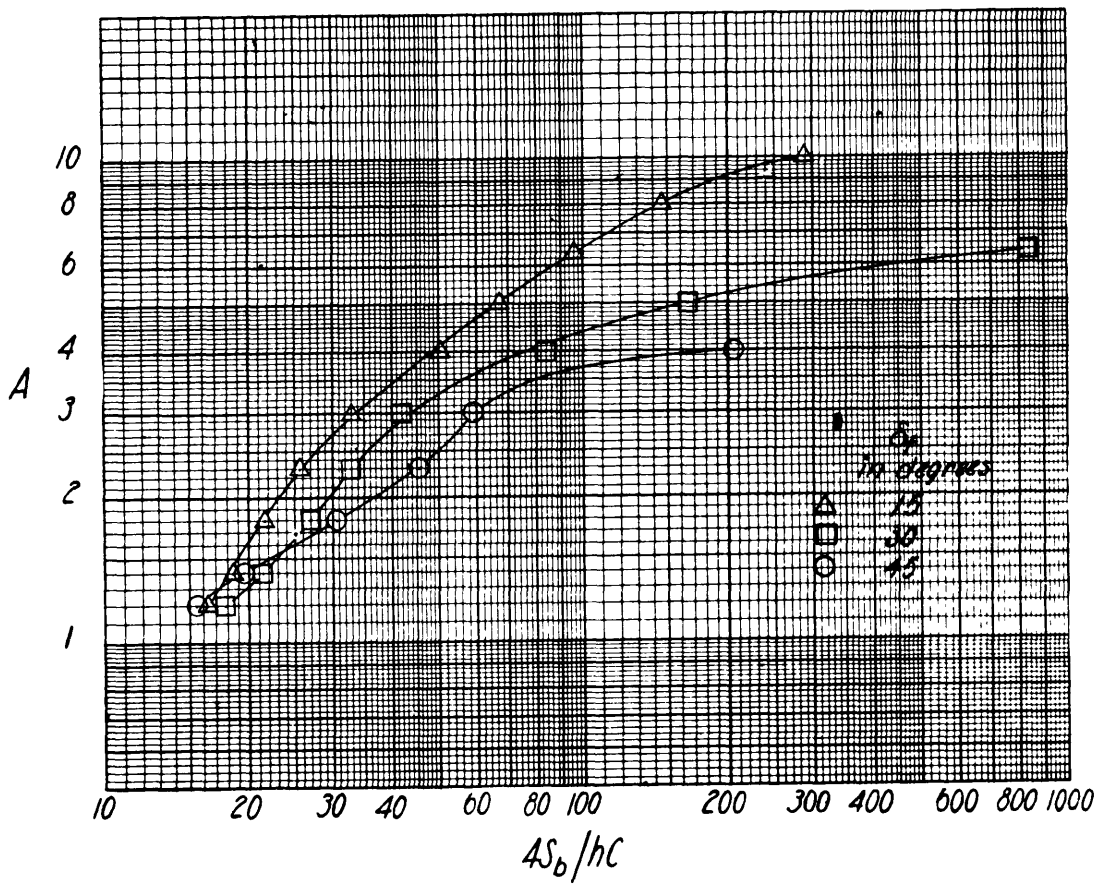

Figure 10 - Variation of Augmentation With Ground Proximity Parameter for Various Values of Flap Deflection Angle

$\theta = -65^\circ$; $\frac{f}{c} = 0.2$; AR = 1