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DAVIDSON LABORATORY

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April 1971

AN EXPERIMENTAL AND THEORETICAL STUDY OF PLANING SURFACES WITH TRIM FLAPS

by

P. Ward Brown

This research was sponsored by the
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Approved

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Assistant Director

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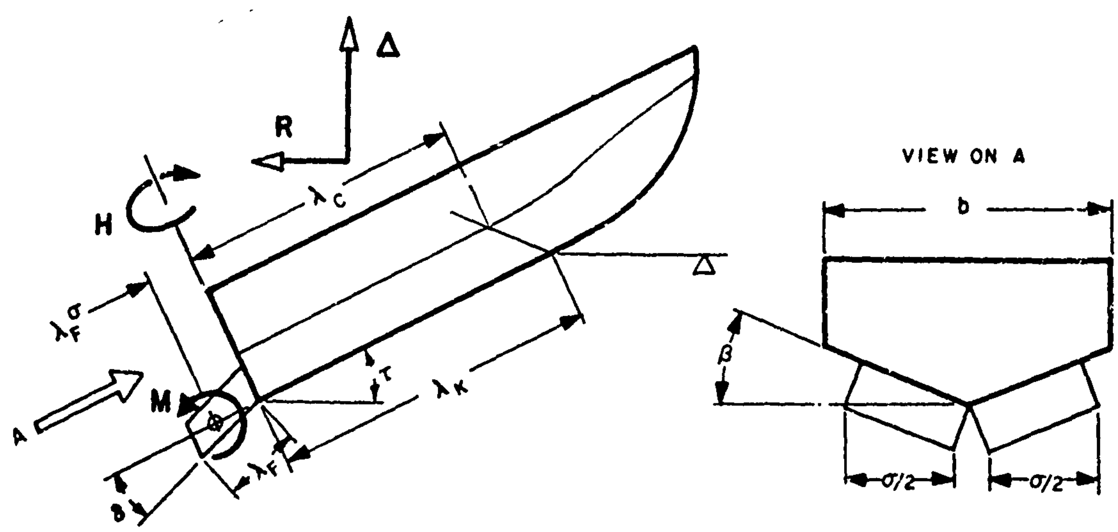
FOREWORD

It is now nearly fifteen years since the results of the last systematic experiments on planing surfaces were published. Those experiments closed an era of research on planing that spanned ten years of the most intensive effort that has so far been devoted to the subject. The original purpose of studies conducted during that period, and indeed of the earlier work on planing, was to serve the needs of the seaplane designer, and for the most part the investigations were directed to that end.

The results contained in the present report are part of a continuing study of planing now being undertaken at the Davidson Laboratory, under the sponsorship of the Office of Naval Research and with additional support from the Naval Ship Systems Command and Naval Ship Research and Development Center. This new program seeks to broaden our understanding of planing, by considering the effects of flaps, deadrise warping, bow form, waves and wider ranges of planing conditions than previously investigated. It is motivated by a desire to provide design information that will better serve the needs of the power-boat designer.

Since the program is thus oriented, and because not everyone will want to wade through details to get at the final results, the more important of these results are summarized in this foreword. Chiefly, they consist of expressions for the lift, drag, pitching moment, and flap hinge moment of a prismatic surface equipped with transom flaps either full-span or part-span, inboard or outboard -- as shown in the following sketch.



The angles are given in degrees, lengths in units of beam and σ is the flap span; for full span flaps $\sigma = 1$.

LIFT

$$C_{L_b} = .785\sin 2\tau\cos\tau \left[(1-\sin\beta)\lambda/(1+\lambda) + .424\lambda\sin 2\tau\cos\beta + .4\sec\tau(\lambda/C_V)^2\right]$$

$$+ \Delta C_{L_{FLAP}}$$

$$\Delta C_{L_{FLAP}} = .046\ \lambda_F\ \sigma\ \delta$$

DRAG

$$C_{D_b} = C_{L_b}\ \tan\tau + C_f\lambda/\cos\tau\cos\beta + \Delta C_{D_{FLAP}}$$

$$\Delta C_{D_{FLAP}} = .00024\ \lambda_F\ \sigma\ \delta(\tau+\delta)$$

MOMENT

$$C_{M_b} = .785\lambda\sin 2\tau \left[(.875\lambda - .08\tan\beta/\tan\tau)(1-\sin\beta)/(1+\lambda)\right.$$

$$\left. + .212\lambda\sin 2\tau\cos\beta + .133\sec\tau(\lambda/C_V)^2\right] + \Delta C_{M_{FLAP}}$$

$$\Delta C_{M_{FLAP}} = 0.6\ \Delta C_{L_{FLAP}}$$

FLAP HINGE MOMENT

$$C_{H_b} = .0032\ \lambda_F^2\ \sigma\ \delta$$

The complexity of these formulae is warranted by their accuracy and should prove no drawback to those with access to a computer. The Davidson Laboratory has developed a power boat performance program, incorporating these formulae, which will predict performance characteristics given the craft weight, beam, deadrise, center of gravity location, flap setting and speed.

To provide for the occasion when paper and pencil estimates are needed, the lift and moment equations have been rewritten in terms of tabulated functions of trim and deadrise:

$$C_\Delta = (F_1/(1+\lambda) + F_2)\lambda C_V{}^2 + F_3\lambda^2 + .023\lambda_F\ \sigma\ \delta\ C_V{}^2$$

$$C_M = \left[G_1(\lambda-G_2)/(1+\lambda)+G_3\lambda\right]\lambda C_V{}^2 + F_3\lambda^3/3 + .014\lambda_F\ \sigma\ \delta\ C_V{}^2$$

$$C_R = C_\Delta\ \tan\tau + C_f\lambda\ C_V{}^2/2\ \cos\tau\ \cos\beta + .00012\lambda_F\ \sigma\ \delta(\tau+\delta)\ C_V{}^2$$

Values for the F and G functions are tabulated below. Performance estimates may be made by an iterative procedure at two or three assumed trim angles. As a starting point it may be assumed that $\lambda = 1.3$ LCG. The iteration proceeds by adjusting λ to achieve a balance between the above hydrodynamic forces and moments and the applied forces and moments.

The performance equations are

$$C_\Delta = C_W - C_T\ \sin(\tau+\theta)$$

$$C_R = C_T\ \cos(\tau+\theta)$$

$$C_M = C_W\left[(LCG+\sigma\lambda_F)\cos\tau - VCG\sin\tau\right] + C_T\left[VT\cos\tau - \sigma\lambda_F\sin\tau\right]$$

where

LCG and VCG are the longitudinal and vertical positions of the CG relative to the keel at transom in units of beam

VT is the height above the keel of the thrust vector at the transom in beams and θ is the angle of the thrust vector in degrees

C_W = Gross weight/wb^3 $\quad$ C_T = Thrust/wb^3 $\quad$ $C_V = V/\sqrt{gb}$

$C_\Delta = \Delta/wb^3$ $\quad$ $C_R = R/wb^3$ $\quad$ $C_M = M/wb^4$ $\quad$ $C_H = H/wb^4$

$C_{L_b} = \Delta/\frac{1}{2}\rho\ V^2b^2$ $\quad$ $C_{D_b} = R/\frac{1}{2}\rho\ V^2b^2$ $\quad$ $C_{M_b} = M/\frac{1}{2}\rho\ V^2b^3$ $\quad$ $C_{H_b} = H/\frac{1}{2}\rho\ V^2b^3$

$= 2\ C_\Delta/C_V{}^2$ $\quad$ $= 2\ C_R/C_V{}^2$ $\quad$ $= 2\ C_M/C_V{}^2$ $\quad$ $= 2\ C_H/C_V{}^2$

These formulae and the tables are a self-contained condensation of the results of this study of flap effectiveness.

FUNCTIØN**F1

TRIM	DEADRISE 0	5	10	15	20	25	30
1	0.0137	0.0125	0.0113	0.0102	0.0090	0.0079	0.0069
2	0.0274	0.0250	0.0226	0.0203	0.0180	0.0158	0.0137
3	0.0410	0.0374	0.0339	0.0304	0.0270	0.0237	0.0205
4	0.0545	0.0498	0.0451	0.0404	0.0359	0.0315	0.0273
5	0.0679	0.0620	0.0561	0.0503	0.0447	0.0392	0.0340
6	0.0812	0.0741	0.0671	0.0602	0.0534	0.0469	0.0406
7	0.0943	0.0861	0.0779	0.0699	0.0620	0.0544	0.0471
8	0.1072	0.0978	0.0886	0.0794	0.0705	0.0619	0.0536
9	0.1199	0.1094	0.0990	0.0888	0.0789	0.0692	0.0599
10	0.1323	0.1207	0.1093	0.0980	0.0870	0.0764	0.0661
11	0.1444	0.1318	0.1193	0.1070	0.0950	0.0834	0.0722
12	0.1562	0.1426	0.1291	0.1158	0.1028	0.0902	0.0781
13	0.1677	0.1531	0.1386	0.1243	0.1104	0.0968	0.0839
14	0.1789	0.1633	0.1478	0.1326	0.1177	0.1033	0.0894
15	0.1897	0.1731	0.1567	0.1406	0.1248	0.1095	0.0948

FUNCTIØN**F2

TRIM	DEADRISE 0	5	10	15	20	25	30
1	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
2	0.0008	0.0008	0.0008	0.0008	0.0008	0.0007	0.0007
3	0.0018	0.0018	0.0018	0.0018	0.0017	0.0016	0.0016
4	0.0032	0.0032	0.0032	0.0031	0.0030	0.0029	0.0028
5	0.0050	0.0050	0.0049	0.0048	0.0047	0.0045	0.0043
6	0.0072	0.0071	0.0071	0.0069	0.0067	0.0065	0.0062
7	0.0097	0.0096	0.0095	0.0094	0.0091	0.0088	0.0084
8	0.0125	0.0125	0.0123	0.0121	0.0118	0.0114	0.0109
9	0.0157	0.0157	0.0155	0.0152	0.0148	0.0142	0.0136
10	0.0192	0.0191	0.0189	0.0185	0.0180	0.0174	0.0166
11	0.0230	0.0229	0.0226	0.0222	0.0216	0.0208	0.0199
12	0.0270	0.0269	0.0266	0.0261	0.0253	0.0244	0.0234
13	0.0312	0.0311	0.0307	0.0301	0.0293	0.0283	0.0270
14	0.0356	0.0355	0.0351	0.0344	0.0335	0.0323	0.0309
15	0.0402	0.0401	0.0396	0.0389	0.0378	0.0365	0.0349

FUNCTIØN**F3

TRIM	ALL DEADRISE
1	0.0054
2	0.0109
3	0.0163
4	0.0217
5	0.0271
6	0.0324
7	0.0377
8	0.0430
9	0.0482
10	0.0534
11	0.0584
12	0.0635
13	0.0684
14	0.0732
15	0.0780

FUNCTIØN**G1

	DEADRISE						
TRIM	0	5	10	15	20	25	30
1	0.0120	0.0109	0.0099	0.0089	0.0079	0.0069	0.0060
2	0.0240	0.0219	0.0198	0.0178	0.0158	0.0138	0.0120
3	0.0359	0.0328	0.0297	0.0266	0.0236	0.0207	0.0180
4	0.0478	0.0437	0.0395	0.0354	0.0315	0.0276	0.0239
5	0.0597	0.0545	0.0493	0.0442	0.0393	0.0345	0.0298
6	0.0714	0.0652	0.0590	0.0530	0.0470	0.0412	0.0357
7	0.0831	0.0759	0.0687	0.0616	0.0547	0.0480	0.0416
8	0.0947	0.0865	0.0783	0.0702	0.0623	0.0547	0.0474
9	0.1062	0.0969	0.0877	0.0787	0.0699	0.0613	0.0531
10	0.1175	0.1073	0.0971	0.0871	0.0773	0.0679	0.0588
11	0.1287	0.1175	0.1064	0.0954	0.0847	0.0743	0.0644
12	0.1398	0.1276	0.1155	0.1036	0.0920	0.0807	0.0699
13	0.1506	0.1375	0.1245	0.1116	0.0991	0.0870	0.0753
14	0.1613	0.1473	0.1333	0.1196	0.1061	0.0931	0.0807
15	0.1718	0.1568	0.1420	0.1273	0.1130	0.0992	0.0859

FUNCTIØN**G2

	DEADRISE						
TRIM	0	5	10	15	20	25	30
1	0.0000	0.4582	0.9235	1.4034	1.9063	2.4423	3.0238
2	0.0000	0.2290	0.4616	0.7015	0.9528	1.2208	1.5115
3	0.0000	0.1526	0.3076	0.4674	0.6349	0.8134	1.0071
4	0.0000	0.1144	0.2305	0.3503	0.4758	0.6096	0.7548
5	0.0000	0.0914	0.1843	0.2800	0.3803	0.4873	0.6033
6	0.0000	0.0761	0.1534	0.2331	0.3166	0.4056	0.5022
7	[illegible]	0.0651	0.1313	0.1995	0.2710	0.3472	0.4299
8	0.0000	0.0569	0.1147	0.1743	0.2368	0.3033	0.3756
9	0.0000	0.0505	0.1018	0.1547	0.2101	0.2692	0.3332
10	0.0000	0.0454	0.0914	0.1389	0.1887	0.2418	0.2993
11	0.0000	0.0411	0.0829	0.1260	0.1712	0.2193	0.2715
12	0.0000	0.0376	0.0758	0.1152	0.1565	0.2006	0.2483
13	0.0000	0.0346	0.0698	0.1061	0.1441	0.1847	0.2286
14	0.0000	0.0321	0.0647	0.0982	0.1335	0.1710	0.2117
15	0.0000	0.0298	0.0602	0.0914	0.1242	0.1591	0.1970

FUNCTIØN**G3

	DEADRISE						
TRIM	0	5	10	15	20	25	30
1	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
2	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
3	0.0009	0.0009	0.0009	0.0009	0.0009	0.0008	0.0008
4	0.0016	0.0016	0.0016	0.0016	0.0015	0.0015	0.0014
5	0.0025	0.0025	0.0025	0.0024	0.0024	0.0023	0.0022
6	0.0036	0.0036	0.0035	0.0035	0.0034	0.0033	0.0031
7	0.0049	0.0049	0.0048	0.0047	0.0046	0.0044	0.0042
8	0.0063	0.0063	0.0062	0.0061	0.0059	0.0057	0.0055
9	0.0080	0.0079	0.0078	0.0077	0.0075	0.0072	0.0069
10	0.0097	0.0097	0.0096	0.0094	0.0092	0.0088	0.0084
11	0.0117	0.0116	0.0115	0.0113	0.0110	0.0106	0.0101
12	0.0138	0.0137	0.0136	0.0133	0.0130	0.0125	0.0119
13	0.0160	0.0160	0.0158	0.0155	0.0150	0.0145	0.0139
14	0.0184	0.0183	0.0181	0.0177	0.0173	0.0166	0.0159
15	0.0208	0.0208	0.0205	0.0201	0.0196	0.0189	0.0180

INTRODUCTION

The Davidson Laboratory is currently conducting a series of systematic experiments on the characteristics of planing surfaces with the object of providing design information pertinent to power boats.

Earlier investigators confined their attentions to prismatic planing surfaces having parallel buttock lines, no bow curvature, and no control surfaces. Their work, which provided a necessary foundation for the present study, has been described by Savitsky[1] and their results have been embodied in various planing formulae which have been critically reviewed by Shuford.[2]

The use of flaps on power boats, either fixed or controllable, has become accepted as a means of controlling the running trim to optimize performance. However, the designer has so far had to rely on experience and on development tests in arriving at his flap configuration. The present study is intended to fill this gap in our knowledge by systemizing the results of experiments with flaps and incorporating their effects in one of the existing sets of planing formulae.

Since the effect of the flaps was expected to take the form of an increase in the hydrodynamic forces and moments, both a flapped and unflapped surface were tested so as to have consistent sets of data. The basic planing surface was a 10° deadrise surface having a 9 inch beam. Full-span and half-span flaps were mounted on this surface through a balance designed to measure the flap hinge moment. The tests were carried out over the following ranges: speed coefficient 1 to 7, trim 2° to 10°, mean wetted length 0.5 to 4 beams, and flap deflection 0° to 15°. The measured quantities included lift, drag, pitching moment, wetted area and flap hinge moment and are presented in tables. The results are summarized by formulae which have been fitted to all the data.

All the data were taken in the planing condition where the water breaks cleanly away from the chine. The effect of side wetting which occurs at very low speed, particularly at high trim and long wetted length, will be discussed in a later report.

NOMENCLATURE

Throughout this report all the measured quantities are normalized with respect to the beam and expressed in the following coefficients:

C_Δ	load coefficient, Δ/wb^3
C_R	resistance coefficient, R/wb^3
C_M	moment coefficient, M/wb^4
C_V	speed coefficient, $V/\sqrt{gb}$
C_H	hinge moment coefficient, H/wb^4
λ	mean wetted length, S/b^2, beams
λ_C	chine wetted length, beams
λ_K	keel wetted length, beams
λ_F	flap chord, beams
σ	flap span, measured in horizontal plane, beams

where

b	beam of planing surface, ft
Δ	lift, vertical component of resultant force, lb
R	drag, horizontal component of resultant force, lb
M	moment of the resultant force about a point on the keel line distance $\lambda_F\sigma$ aft of the transom, ft-lb
V	horizontal velocity, fps
H	flap hinge moment measured about an axis formed by the intersection of the bottom and transom, ft-lb
S	projected wetted area bounded by the stagnation line, chines and transom measured in a plane which is normal to the centerplane and contains the keel, sq.ft.
w	specific weight of water, lb per cu.ft.
g	acceleration due to gravity, fps^2

Also

C_{L_b} lift coefficient, $\Delta/\frac{1}{2}\rho V^2 b^2 = 2\, C_\Delta/C_V{}^2$

C_{D_b} drag coefficient, $R/\frac{1}{2}\rho V^2 b^2 = 2\, C_R/C_V{}^2$

C_{M_b} moment coefficient, $M/\frac{1}{2}\rho V^2 b^3 = 2\, C_M/C_V{}^2$

C_{H_b} hinge moment coefficient, $H/\frac{1}{2}\rho V^2 b^3 = 2\, C_H/C_V{}^2$

C_f Schoenherr turbulent skin friction coefficient,

$$\log (C_f Re) = .242/\sqrt{C_f}$$

C_p center of pressure position, distance along the keel from the transom to the intersection of the resultant force vector with the keel, as a fraction of the mean wetted length:

$$C_M/(\lambda+\sigma\lambda_F)(C_\Delta \cos\tau + C_R \sin\tau)$$

Re Reynolds Number, $\lambda C_V \sqrt{gb^3}/\nu$

β deadrise angle, angle of a line joining the keel to the lowest point of the chine (including a spray strip if fitted) measured in the transverse plane, deg

δ flap deflection angle, measured in a longitudinal plane normal to the bottom surface, deg

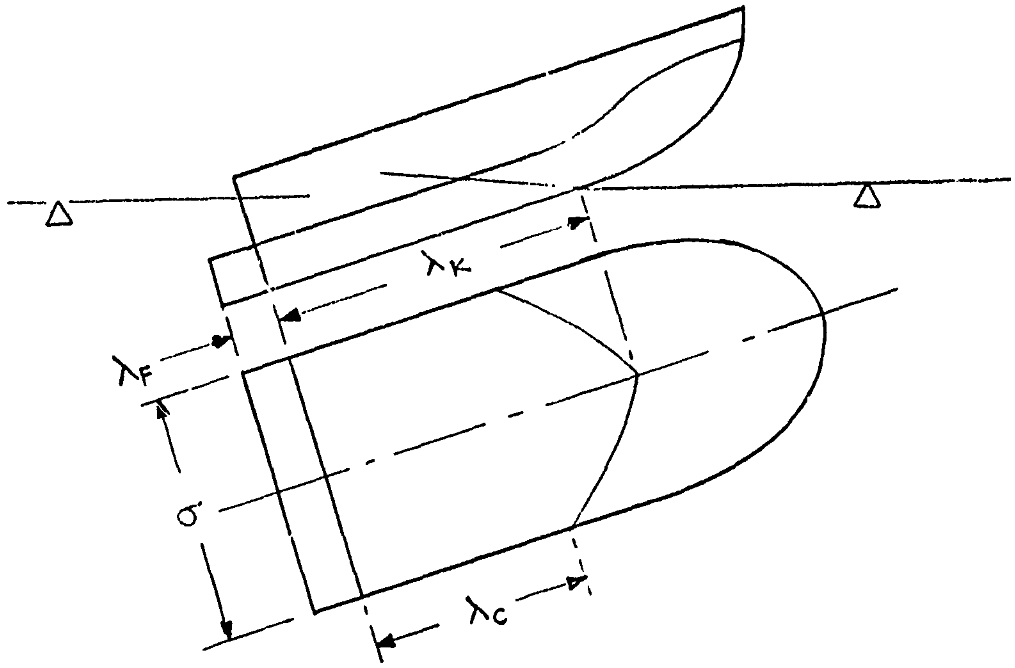
τ trim angle, angle between the keel and the horizontal, deg

ρ mass density of water, slugs per cu.ft.

ν kinematic viscosity of water, f^2ps

Mean Wetted Length

The mean wetted length is a fundamental quantity in planing analysis and is derived from the wetted area projected on a plane normal to the centerplane and containing the keel. The wetted area is bounded in front by the stagnation line, which is slightly convex forward, and by the chines and transom as shown in the following sketch:



The mean wetted length is equal to the average of the chine and keel lengths plus an allowance for the stagnation line curvature and for the flaps if fitted. Analyzing the results of wetted area measurements with a 1 ft beam transparent model the author has shown[3] that:

$$\lambda = 0.5(\lambda_K + \lambda_C) + 0.03\ \lambda_F\sigma$$

From an analysis of all the available data it is concluded in the same study[3] that the relationship between the keel and chine wetted lengths is given by

$$\lambda_K - \lambda_C = (0.57 + 0.001\ \beta)(\tan\beta/2\ \tan\tau - 0.006\beta)$$

provided $\lambda_C \geq 1$. For lesser chine wetted lengths Reference 3 should be consulted.

MODELS

The planing surface used in this investigation was a 10° deadrise surface having a beam of 0.75 ft and an overall length of 5.6 beams. The surface was made of half inch thick transparent plexiglass with the sides above the chines machined square to the bottom surface so as to obtain a sharp corner. Shuford[2] has shown that a chine radius of as little as 1/64 inch will degrade the lift by 5%. Keel, chine and quarter beam buttock lines were painted on the bottom with transverse marks at 0.1 beam pitch for the purpose of measuring wetted length. The planing surface was mounted on a rigid aluminum support frame to prevent model deflection and to provide for attachment to the apparatus. A photograph of the planing surface is included on Fig 1.

The transom flaps were made of aluminum blocks with the lower surface machined to the required flap angle to ensure its being accurately maintained. The port flap was rigidly attached to the planing surface while the starboard flap was attached to the surface through a hinge moment balance. The following flaps were made:

Flap Chord	Span	Flap Angle
20% beam	Full	0,1,2,4,10,15
	Half	1,2,4
10% beam	Full	1,2,4
	Half	1,2,4

The half span flaps were made interchangeable so that they could be tested in either the inboard or outboard condition. The inboard flaps extended a quarter of a beam either side of the keel, while outboard flaps extended from the quarter beam buttock line to the chine on both the port and starboard side. A photograph of some of the flaps and the hinge moment balance appears at the bottom of Fig 1.

APPARATUS

The forces and moments on the planing surface were measured by a three component balance having a nominal capacity in lift, drag and pitching moment of 100 lb, 50 lb and 50 ft-lb. The lift and moment range can be extended by deadweighting. The moment element of the balance has a focus 12 inches below the bottom of the balance and this location is used as the trim axis. The deflections of the balance under load are sensed by transducers. The transducers are linear differential transformers with self-contained solid state electronics, of a type known as DC/DC, and are highly stable. The outputs of the transducers are fed to integrating digital voltmeters having a precision of 0.01%. Flexure-supported lift and drag calibrating arms are permanently fixed to the balance and a beam is attached to the balance for moment calibration. The balance is shown at the top of Fig 2.

A hinge moment balance of a similar type was attached at the transom of the model for the flap tests, and is shown with the flaps on Fig 1.

The dynamic wetted areas were measured from overwater photographs of the planing surface using the technique developed by the writer.[4] The photographs were taken by a "Polaroid" camera, mounted above the transparent model and travelling with it, against an illuminated background. An example of the results obtained with this technique is shown at the bottom of Fig 2.

TEST PROCEDURE AND PROGRAM

The tests were run in the Davidson Laboratory No. 3 Tank at constand speed with the model at zero roll and yaw and restrained in heave and pitch.

A new testing technique was used in these experiments. The forces on a planing surface are a function of three independent variables: the speed, the trim and the mean wetted length. In analyzing the planing data accumulated prior to 1949, Korvin-Kroukovsky[5] pointed out the need to assign a series of discrete values to the independent variables and commented that failure to do so "resulted in the accumulation of data which are extremely difficult to correlate." Earlier investigators, while using discrete value of speed and trim, have allowed the wetted lengths to assume random values. Since the writer subscribes to the view that the independent variables should be controlled, the model was completely restrained and the mean wetted length was held constant at discrete levels during changes in speed and trim. A subsidiary investigation, which will be reported separately, showed the forces to be the same using either the restrained technique or the previously used free-to-heave technique. Since the planing forces and moments vary as the square of the speed these tests were made at discrete values of speed squared.

The model was attached to the balance by a trim adjuster, the trim (and moment) axis being 2.61 beams ahead of the step and .88 beams above the keel. The fore and aft location was chosen to minimize the pitching moment on the balance.

In a preliminary investigation it was found that pitching moments caused a deflection of the balance that significantly altered the model trim. The change in trim due to this deflection was determined and allowed for in setting the trim of the model before each run. The aerodynamic tares were determined by towing the model just above the water surface at various trims and speeds. Only the hinge moment and drag were affected by air flow, and their tares have been removed from the data.

For each run the model was set at the required trim, with allowance for the estimated moment deflection, and the zeros in air were recorded. The height of the model and balance assembly was then adjusted by means of jack screws to give an immersion which would result in the required mean wetted length. The model was run at the required speed, which was measured by a timer over a 50 foot length of tank. The integrating voltmeters, lights and camera were all triggered automatically and the resulting readings were recorded. The model is shown setup for test in Fig 3.

For the unflapped planing surface the following discrete levels of the independent variables were investigated:

$$C_V^2 = 1,5,10,20,30,40,50$$

$$\tau = 2,4,6,8,10 \text{ degrees}$$

$$\lambda = 0.5,,1,1.5,2,3,4$$

However some combinations were omitted as being unnecessary. For the flapped surface the following levels were used:

C_V^2 = 10,20,30,40,50

τ = 4,6,8 degrees

λ = 2,4

δ = 1,2,4,10,15 degrees

RESULTS

The results of the tests of the basic planing surface are presented in Table 1 and the results obtained with flaps in Table 2. The data are ordered by trim and wetted length and at each condition the results are listed in order of speed. The tabulated quantities include the trim, corrected for balance deflection; the mean, keel and chine wetted lengths; the lift, drag and the total moment about the aftermost point of the keel and the flap hinge moment. The lift, drag and pitching moment are plotted on Figs 4 to 14.

The results have also been stored on perforated tape suitable for computer input. Consequently any alternative listing or analysis of the data may be readily produced.

PRECISION

From the repeat runs available and from a general knowledge of the apparatus the precision of the data is estimated to be

Trim	$\pm$ .01 deg
Wetted length	$\pm$ .01 beam
C_Δ	$\pm$ .01
C_R	$\pm$ .002
C_M	$\pm$ .02
C_H	$\pm$ .00005

ANALYSIS

The fundamental property of a planing surface is the lift it generates because its other properties - the drag and moment - are essentially functions of the lift. Thus the analysis begins with a discussion of the lift, followed by discussion of the drag and pitching moment. A subsequent section deals with the effect of the flaps on the planing characteristics.

Lift

The lift on a planing surface can be attributed to two separate effects - one due to the dynamic pressure of the water against the moving surface and the other ascribable to the hydrostatic pressure associated with a given hull draft and attitude. Thus the lift on a planing surface is said to be made up of dynamic and static components:

$$C_{\Delta} = C_{\Delta_D} + C_{\Delta_S} \tag{1}$$

By definition the dynamic lift varies as the square of the speed and the static lift is invariant with speed, so that for given wetted length and trim

$$C_{\Delta} = m\, C_V^{\,2} + C_{\Delta_S}, \quad (\lambda, \tau) = \text{constant} \tag{2}$$

We can find the static component by plotting the lift against the square of the speed, as suggested by Eq (2), when the static lift may be found as the intercept on the lift axis. The data obtained from the 10° deadrise surface at trims of 2° to 10° are presented in this form on Figs 4 to 8 for mean wetted lengths of 0.5, 1, 2, 3 and 4. The ratio of lift to trim, in the form $C_{\Delta}/\sin 2\tau$, is plotted to give a compact presentation.

The static lift of a planing surface with deadrise, due to the hydrostatic pressure on the bottom, is theoretically given by

$$C_{\Delta_S} = 0.25\,\lambda^2 \sin 2\tau \left[1 + (\lambda_K - \lambda_C)^2/12\,\lambda^2\right] \quad (3)$$

where λ_K and λ_C are the keel and chine wetted lengths and λ is the mean wetted length. Since the last factor is close to unity we can assume that

$$C_{\Delta_S} = 0.25\,\lambda^2 \sin 2\tau \quad (4)$$

As the planing surface starts to move, however, the water breaks clear of the transom at speeds above $C_V = 0.5$ so that the pressure at this point drops to atmospheric. Therefore it is not expected that the full amount of static lift will be realized. From the intercepts on Figs 4 to 8 it is found that the data are well fitted by

$$C_{\Delta_S} = 0.156\,\lambda^2 \sin 2\tau \quad (5)$$

Savitsky made a study[6] of the low-speed performance of planing surfaces and proposed the following expression for the static lift

$$C_{\Delta_S} = .236\,\tau^{1.1}\,\lambda^{2.5}(1 - .221\beta/\tau^{.44}\,\lambda^{.2}) \quad (6)$$

where the trim and deadrise are in radians. Shuford[2] tentatively proposed an expression approximately equal to half that given by Eq (3), based on tests of models having a 1.0 inch beam, but found it inadequate for trims less than 8°.

The dynamic component of planing lift is measured by the slopes of the lines on Figs 4 to 8, since from Eqs (1) and (2), $C_{\Delta_D} = m\,C_V^{\,2}$. Two formulations for dynamic lift have found wide acceptance. The older of these, developed by Korvin-Kroukovsky,[5] is derived in a definitive study of planing that systemizes all the planing data available prior to 1949. This formulation for the lift that is speed dependent, that is to say for the dynamic lift, gives:

$$C_{\Delta_D}/C_V^{\,2} = .515\,\tau^{1.1}\,\lambda^{.5} - .190\beta\,\tau^{.66}\,\lambda^{.3}$$

$$+\ .005\beta\,\tau^{.66}\,\lambda^{.3}(\lambda/C_V)^4\left[1 + \text{Terms } 0(\lambda/C_V)^2\right] \quad (7)$$

where again the angles are measured in radians. The existence of the third term in this expression is superfluous and makes a very small contribution at all practical conditions. The superfluous term arises from the way in which the finite-deadrise lift coefficient is expressed by Korvin-Kroukovsky. In view of the extensive use of this expression, its derivation is worthy of comment. Korvin-Kroukovsky and his co-workers were aware of more sophisticated lift formulations than that finally proposed. However they were concerned to present their findings in a compact form suitable for hand computation and achieved their aim by using a frankly empirical approach. Basing their study primarily on the mass of flat-plate planing data available, they subsequently developed an empirical correction to account for the effect of deadrise. This correction produced the superfluous third term in the dynamic lift expression. As noted, this third term is of little practical significance. What is significant is the development of high-speed computers, which has largely obviated the need for compactness and simplicity of expression.

The second established formulation for dynamic lift is due to Shuford.[2] Based on data obtained by the NACA using 4-inch beam models at very high speed, and on the results of his own extension of the test program to extreme trims and high wetted lengths, Shuford proposed for the dynamic lift:

$$C_{\Delta_D}/C_V^2 = .785\ \sin\tau\cos^2\tau(1-\sin\beta)\ \lambda/(1+\lambda) + .667\lambda\ \sin^2\tau\cos^2\tau\ \cos\beta \tag{8}$$

Shuford's dynamic lift formulation is made up of two terms. The first one said to be linear term, and derived from lifting-line theory, and the second a cross-flow term dependent on the square of the trim. The analogue to this cross-flow component in Korvin-Kroukovsky's expression is represented by the factor $\tau^{0.1}$. It is possible to compare the leading terms of these two expressions by noting that for $1 < \lambda < 4$, which is the range of applicability of Eq (7):

$$.515\ \lambda^{.5} = 1.153\ \lambda(1+\lambda) \quad \text{within} \pm 10\%$$

Thus the linear terms in the two dynamic lift expressions, for small trim and zero deadrise, are

Korvin-Kroukovsky: $C_{\Delta_D}/C_V{}^2 = 1.153\tau\ \lambda(1+\lambda)$

Shuford: $C_{\Delta_D}/C_V{}^2 = .785\tau\ \lambda(1+\lambda)$

The older expression has the larger coefficient presumably to remedy the defect in the cross-flow term. However it is not surprising that Shuford shows even this 50% increase in the linear term is insufficient to account for all the lift at high trim and wetted length.

We now have to choose between two formulations for the total lift. From Korvin-Kroukovsky and Savitsky we have:

$$C_\Delta/C_V{}^2 = 0.5\ C_{L_o} - .0035\beta\ C_{L_o}^{.6} \qquad (9)$$

where

$$C_{L_o}/\tau^{1.1} = .012\ \lambda^{.5}\left[1 + .458(\lambda/C_V)^2\right]$$

and now the angles τ and β are in degrees. On the other hand we can use Shuford's expression, Eq (8), for the dynamic lift plus a static term given by Eq (5) and obtain a Shuford and Brown formulation:

$$\frac{C_\Delta/C_V^2}{\sin 2\tau} = .393\left[\cos\tau(1-\sin\beta)\lambda/(1+\lambda) + .849\lambda\sin\tau\cos^2\tau\cos\beta + .4(\lambda/C_V)^2\right] \qquad (10)$$

These two expressions are compared with the lift data obtained in the present study on Figs 4 to 8. It is clear that the Shuford-Brown formula, Eq (10), gives a better fit to the data.

Shuford has also demonstrated[2] close agreement between his formula for the dynamic lift and the high-speed data obtained by such investigators as Sottorf, Sambraus, Locke, Wadlin, Weinstein, Kapryan, Chambliss, Farshing and Springston. This agreement covers a range of trim angles from 2^o to 30^o, wetted lengths from 1 to 7 beams and deadrise angles from 0^o to 50^o with provision for transverse curvature.

We shall therefore adopt Eq (10) as the best existing planing lift formulation, its most general form being:

$$C_{L_b} = (\pi/4)\sin 2\tau\cos\tau\left[(1-\sin\beta)\lambda/(1+\lambda)+(C_{D_c}/\pi)\lambda\sin 2\tau\cos\beta + 0.4\sec\tau(\lambda/C_V)^2\right] \qquad (11)$$

The cross-flow drag coefficient, C_{D_c} , has the following values[2]

Section Shape	C_{D_c}
Plane surface, any deadrise	1.33
Plane surface with vertical chine strips	$1.67 + .93 \sin\beta$
Curved surface with horizontal chine flare	$1.33 + .93 \sin\beta$

Drag

The hydrodynamic forces on a planing surface are due to dynamic and static pressures acting normal to the surface and to viscous shear stresses acting parallel to the surface. If we resolve these normal and tangential forces into lift and drag, and assume that the shear stress depends on the total wetted area, we can show that

$$C_{D_b} = C_{L_b} \tan\tau + C_f \lambda/\cos\tau \cos\beta \tag{12}$$

The determination of the planing surface skin friction coefficient is difficult both experimentally and theoretically. We shall simply assume that the skin friction coefficient is given by Schoenherr's formula for fully turbulent flow

$$.242/\sqrt{C_f} = \log(C_f \, Re) \tag{13}$$

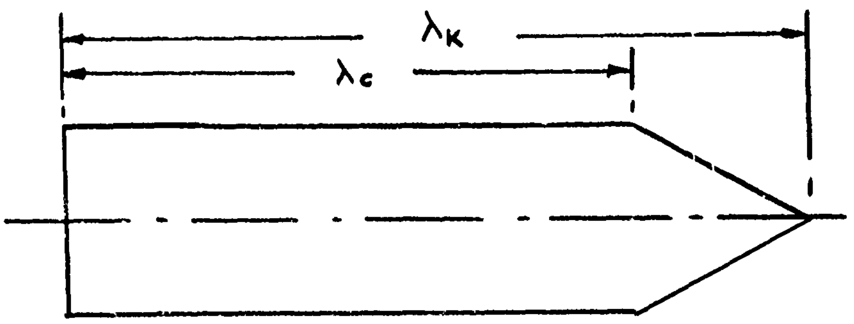
The resistance data in the form $C_R/\sin 2\tau$ are plotted as a function of the speed squared on Figs 9 to 11. The lines drawn through the data are from Eq (12), with C_{L_b} from Eq (11), C_f from Eq (13) and $C_R = C_{D_b} C_V^2/2$. Clearly this simple analysis agrees closely with the data.

Moment

The pitching moments on the planing surface about the transom-keel intersection are due to the normal pressures referred to above. The friction forces are not only comparatively small but their line of action passes so close to the keel that they may be assumed not to contribute to the moment.

Now the lift, which is essentially the vertical component of the normal pressures, is made up of three terms: a linear term, a cross-flow term and a static term. We assume that the static force acts at a point one-third of the wetted length ahead of the step and that the cross-flow force acts at the mid-point of the wetted length. With these approximate assumptions we can find the center of pressure of the linear force from the data.

The planform of the deadrise planing surface looks like this:



If all the so-called linear lift were concentrated over the leading triangular area (as low aspect-ratio theory requires) and if furthermore it were uniform over this area, then the moment arm of the linear force would be:

$$cp_{LIN} = \lambda_C + .333(\lambda_K - \lambda_C)$$
$$= \lambda \ - .167(\lambda_K - \lambda_C)$$

since $\lambda \simeq 0.5(\lambda_K + \lambda_C)$. However $(\lambda_K - \lambda_C)$ is proportional to $\tan\beta/\tan\tau$ so we might expect that

$$cp_{LIN} = A\lambda - B \tan\beta/\tan\tau$$

Analysis of the present data shows that $A = .875$ and $B = 0.08$. Shuford found the same value for A , but omitted the second term probably because he was concentrating on high trims and long wetted lengths where the effect of the second term is small.

Knowing the moment arms of the three components of the lift, which is the vertical component of the normal force, we can write down the moment from Eq (11):

$$C_{M_b} = (\pi/4)\lambda \sin 2\tau \left[(.875\lambda - .08\tan\beta/\tan\tau)(1-\sin\beta)/(1+\lambda) \right.$$

$$\left. + (C_{D_c}/2\pi)\lambda \sin 2\tau \cos\beta + .133 \sec\tau(\lambda/C_V)^2 \right] \qquad (14)$$

The moment data are compared with Eq (14) on Figs 12 to 14 in the form $C_M/\sin 2\tau$ versus C_V^2.

Flap Effects

The increase in the lift, drag and pitching moment with flap deflection is readily found by subtracting the force and moment for zero flap deflection, Eqs (11), (12) and (14), from the measured force and moment. In the case of the lift, for instance, an average lift coefficient increment is defined:

$$\Delta C_{L_{FLAP}} = 2 \Sigma (C_{\Delta_F} - C_{\Delta_o})/\Sigma C_V^2$$

where C_{Δ_F} is the measured lift with flap deflection, and C_{Δ_o} is the unflapped lift calculated from Eq (11). Corresponding quantities for drag, pitching moment and hinge moment are similarly defined and presented in Table 3.

Lift

The increase in lift due to flap deflection is a function of both the flap area and the amount of the deflection. Consequently the increase is plotted in the form $\Delta C_{L_{FLAP}}/\lambda_F\sigma$ as a function of the flap angle on Fig 15. Although the flap deflection affects the planing surface pressure distribution for some distance ahead of the flap, the results taken with wetted lengths of 2.2 and 4.2 lie on the same line. Thus it may be concluded that the flap effect extends over a constant area of the surface.

From Fig 15 we find

$$\Delta C_{L_{FLAP}} = .046 \lambda_F \sigma \delta \qquad (15)$$

Drag

Since the lift is increased by flap deflection it follows that the induced drag is increased. But this does not account for all the increase in drag due to flap deflection. There is in addition an increase in the pressure on the flap itself and this increase, multiplied by $\sin(\tau+\delta)$ further augments the drag. The data are plotted on Fig 16 from which we find the flap drag to be:

$$\Delta C_{D_{FLAP}} = .00024\ \lambda_F \sigma\ \delta\ (\tau+\delta) \tag{16}$$

Pitching Moment

If our analysis of the lift due to flap is correct, and a constant area of the surface is affected, we might expect the added lift to act at a fixed point. This hypothesis is borne out by Fig 17 since it shows that

$$\Delta C_{M_{FLAP}} = 0.6\ \Delta C_{L_{FLAP}} \tag{17}$$

Thus regardless of flap area or deflection, the added lift has a center of pressure 0.6 beams ahead of the trailing edge of the flap.

Hinge Moment

The hinge moment per flap, that is the torque necessary to maintain the flap deflection against the hydrodynamic pressure on the flap, is shown on Fig 18 to be:

$$C_{H_b} = .0032\ \lambda_F^{\ 2}\ \sigma\ \delta \tag{18}$$

The shear loads were not measured, but the flap center of pressure is probably $\lambda_F/3$ aft of the flap hinge. If so, the shear load coefficient would be $.0096\ \lambda_F\ \sigma\ \delta$.

Flap Location

The location of the flaps, whether inboard or outboard, makes no discernible difference to the increments in the forces and moments as shown on Figs 15 to 18.

CONCLUDING REMARKS

This study concludes with the development of the formulae for the planing characteristics of a surface equipped with transom flaps. The formulae offer a number of opportunities for design studies of flap effect on, for instance, lift-drag ratio and center of pressure position; but these questions must be left for another occasion. At the same time it should be noted that the formulae have been incorporated in computer programs developed by the Davidson Laboratory for power boat performance prediction, consequently the flap effect in any specific situation can be easily demonstrated.

In this report Shuford's expression for dynamic lift is adopted in preference to Korvin-Kroukovsky's. This decision was not taken lightly. Since the older expression was developed at the Davidson Laboratory and has been used and advocated by the Laboratory for the past 20 years a word of explanation is in order. There has never been a lack of expressions for the lift of planing surfaces; Shuford in his review takes note of no less than five different equations, and these are only the more recent ones. Of course each author demonstrated satisfactory agreement between his equations and the data available to him, and yet there was little functional similarity between the several expressions. In one important respect however they were similar. They were only to be used at high speed. Korvin-Kroukovsky's formulation, with the extensions added by Savitsky, was exceptional in that it was the only one designed for use down to $C_V = 1.0$. Moreover Korvin-Kroukovsky and Savitsky presented expressions for drag and center of pressure, which were omitted from other planing equations.

The differences between the old and new formulations are of the order of 10% in the region germane to power boats, and this does not seem an excessive discrepancy in view of other uncertainties associated with performance prediction. Such topics as power plant performance and propeller efficiency come to mind. On the other hand, the most accurate available formula had to be used in the present study if the flap effects were to be properly isolated. It is clear that Shuford's formula for dynamic lift plus the static lift term developed herein gives a better representation of the new data. This consideration and the facts that Shuford's expression has a reasonable theoretical foundation and has been shown to agree with data covering the widest range of conditions, persuaded us that a change was timely.

Finally a word as to the range of applicability of the formulae. At very low speeds the water clings to the chines and the hull sides are wetted, this regime is the subject of a separate study. On the basis of the preliminary results of this low speed work it appears that the present formulations may be used provided that $C_V \geq 0.7$.

The various formulae are summarized below

Range of Application

$$C_V \geq 0.7 \qquad \lambda \geq 1 \qquad 0^\circ \leq \beta \leq 50^\circ \qquad 0^\circ \leq \tau \leq 30^\circ \qquad 0^\circ \leq \delta \leq 15^\circ$$

Lift

$$C_{L_b} = .25\pi \sin 2\tau \cos\tau \left[(1-\sin\beta)\lambda/(1+\lambda) + (C_{D_c}/\pi)\lambda \sin 2\tau \cos\beta + 0.4\sec\tau)\lambda/C_V)^2\right] + \Delta C_{L_{FLAP}}$$

$$\Delta C_{L_{FLAP}} = .046\lambda_F \, \sigma \, \delta$$

For a plane surface, one with chine flare, and one with chine strips the cross-flow factor respectively is $C_{D_c} = 1.33,\ 1.67 + .93 \sin\beta,\ 1.33 + \sin\beta$

Drag

$$C_{D_b} = C_{L_b} \tan\tau + C_f\lambda/\cos\tau \, \cos\beta + \Delta C_{D_{FLAP}}$$

$$\Delta C_{D_{FLAP}} = .00024 \, \lambda_F \, \sigma \, \delta(\tau+\delta)$$

Moment

$$C_{M_b} = .25\pi\ \lambda \sin 2\tau \Big[(.875\lambda - .08\tan\beta/\tan\tau)(1-\sin\beta)/(1+\lambda)$$

$$+ (C_{D_c}/2\pi)\lambda \sin 2\tau \cos\beta + .133\sec\tau(\lambda/C_V)^2\Big] + \Delta C_{M_{FLAP}}$$

$$\Delta C_{M_{FLAP}} = 0.6\ \Delta C_{L_{FLAP}}$$

Hinge Moment per Flap

$$C_{H_b} = .0032\ \lambda_F^{\ 2}\ \sigma\ \delta$$

ACKNOWLEDGEMENT

The experiments reported herein were conducted by Mrs. Ann Ljone. The tasks of setting the pitch and heave so as to achieve desired values of trim and wetted length were also her responsibility and the tables testify to the care with which this was carried out.

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TABLE 1

UNFLAPPED DATA

τ	λ	λ_K	λ_C	C_V^2	C_Δ	C_R	C_M
TRIM = 2 DEG			MEAN WETTED LENGTH = 1.0 BEAMS				
1.99	1.03	1.73	0.28	4.99	0.07	0.015	0.07
1.97	0.97	1.65	0.24	9.86	0.13	0.027	0.11
1.95	0.99	1.69	0.23	20.36	0.26	0.055	0.20
1.92	0.98	1.70	0.21	30.49	0.39	0.074	0.29
1.90	1.00	1.72	0.23	39.32	0.50	0.096	0.38
1.87	1.00	1.73	0.21	50.48	0.62	0.127	0.47
TRIM = 2 DEG			MEAN WETTED LENGTH = 2.0 BEAMS				
1.98	2.02	2.79	1.20	5.01	0.13	0.033	0.17
1.97	2.01	2.77	1.20	9.94	0.21	0.052	0.29
1.95	1.95	2.71	1.13	20.29	0.37	0.088	0.51
1.95	2.07	2.86	1.23	20.09	0.38	0.092	0.54
1.92	2.04	2.83	1.20	30.08	0.54	0.134	0.77
1.92	1.94	2.73	1.10	30.17	0.53	0.128	0.72
1.90	1.97	2.80	1.08	40.16	0.68	0.171	0.95
1.88	1.99	2.82	1.10	49.92	0.82	0.203	1.13
TRIM = 2 DEG			MEAN WETTED LENGTH = 3.0 BEAMS				
1.97	3.04	3.82	2.21	9.86	0.29	0.071	0.54
1.96	3.03	3.85	2.16	20.27	0.48	0.126	0.94
1.94	3.04	3.83	2.20	29.92	0.66	0.178	1.32
1.93	3.01	3.85	2.12	39.94	0.84	0.227	1.68
1.92	3.01	3.85	2.12	50.98	1.03	0.286	2.09
TRIM = 2 DEG			MEAN WETTED LENGTH = 4.0 BEAMS				
1.97	4.05	4.80	3.25	9.89	0.42	0.097	0.92
1.98	4.02	4.78	3.20	20.18	0.61	0.157	1.48
1.97	3.97	4.70	3.19	29.92	0.80	0.224	2.03
1.97	3.95	4.73	3.12	50.27	1.20	0.357	3.13

TABLE I continued

τ	λ	λ_K	λ_C	C_V^2	C_Δ	C_R	C_M
TRIM = 4 DEG			MEAN WETTED LENGTH = 0.5 BEAMS				
4.00	0.48	0.82	0.09	0.85	0.02	0.007	0.03
4.00	0.49	0.82	0.11	1.07	0.02	0.009	0.03
3.98	0.53	0.88	0.12	5.09	0.11	0.023	0.07
3.95	0.51	0.85	0.11	10.10	0.21	0.031	0.13
3.91	0.51	0.86	0.11	20.00	0.42	0.049	0.22
3.87	0.49	0.83	0.10	30.74	0.60	0.066	0.28
3.87	0.49	0.83	0.09	31.67	0.61	0.060	0.27
3.82	0.50	0.85	0.09	42.89	0.80	0.091	0.35
3.78	0.52	0.88	0.10	53.58	1.00	0.139	0.48
TRIM = 4 DEG			MEAN WETTED LENGTH = 1.5 BEAMS				
3.99	1.47	1.86	1.03	0.45	0.04	0.016	0.04
3.99	1.52	1.90	1.09	0.80	0.06	0.018	0.05
3.94	1.54	1.89	1.13	10.14	0.38	0.057	0.43
3.89	1.48	1.83	1.08	20.09	0.69	0.100	0.76
3.83	1.49	1.85	1.08	31.77	1.06	0.146	1.18
3.78	1.46	1.83	1.04	43.09	1.39	0.201	1.54
3.78	1.47	1.84	1.04	43.09	1.38	0.203	1.52
3.73	1.50	1.87	1.08	53.97	1.69	0.266	1.93
TRIM = 4 DEG			MEAN WETTED LENGTH = 2.0 BEAMS				
3.96	2.01	2.37	1.60	5.24	0.27	0.036	0.37
3.94	2.02	2.39	1.60	9.98	0.44	0.068	0.63
3.94	2.02	2.38	1.60	11.16	0.48	0.067	0.68
3.90	1.99	2.35	1.58	19.65	0.79	0.119	1.14
3.90	1.98	2.32	1.58	20.00	0.80	0.119	1.17
3.85	2.00	2.35	1.59	31.60	1.18	0.188	1.72
3.85	2.00	2.35	1.59	31.95	1.21	0.186	1.76
3.84	1.96	2.33	1.54	32.67	1.23	0.186	1.77
4.00	2.13	2.46	1.74	40.09	1.58	0.254	2.54
3.81	2.03	2.40	1.60	43.37	1.57	0.262	2.35
3.96	2.08	2.40	1.71	49.82	1.91	0.312	3.03
3.76	2.01	2.40	1.57	53.97	1.90	0.329	2.84
3.77	2.06	2.45	1.61	53.97	1.92	0.332	2.93
TRIM = 4 DEG			MEAN WETTED LENGTH = 3.0 BEAMS				
3.95	3.03	3.37	2.64	9.98	0.62	0.093	1.21
3.93	3.02	3.37	2.62	20.05	1.04	0.164	2.12
3.91	3.00	3.34	2.60	29.92	1.46	0.237	3.04
3.89	3.01	3.37	2.60	40.19	1.87	0.310	3.96
3.87	3.03	3.40	2.61	50.27	2.29	0.379	4.92
TRIM = 4 DEG			MEAN WETTED LENGTH = 4.0 BEAMS				
3.97	3.99	4.33	3.60	9.92	0.85	0.120	1.96
3.98	3.99	4.33	3.60	19.96	1.31	0.208	3.36
3.99	3.99	4.32	3.60	30.04	1.79	0.297	4.74
4.00	4.00	4.34	3.60	39.94	2.30	0.389	6.22
4.00	3.98	4.31	3.60	50.24	2.78	0.483	7.62

TABLE 1 continued

τ	λ	λ_K	λ_C	C_V^2	C_Δ	C_R	C_M
TRIM = 6 DEG			MEAN WETTED LENGTH = 1.0 BEAMS				
5.96	1.00	1.23	0.72	4.96	0.23	0.032	0.19
5.92	1.04	1.25	0.77	9.90	0.46	0.061	0.38
5.83	1.00	1.22	0.72	20.00	0.88	0.117	0.68
5.76	1.00	1.23	0.71	29.34	1.27	0.164	0.98
5.68	0.99	1.23	0.70	39.81	1.69	0.226	1.30
5.61	0.97	1.21	0.68	49.48	2.01	0.262	1.47
5.61	0.98	1.21	0.69	49.96	2.04	0.269	1.51
TRIM = 6 DEG			MEAN WETTED LENGTH = 2.0 BEAMS				
5.95	2.00	2.22	1.73	5.10	0.41	0.066	0.57
5.91	2.05	2.28	1.77	9.86	0.70	0.101	1.02
5.91	2.06	2.29	1.78	9.95	0.70	0.103	1.03
5.85	2.06	2.29	1.78	20.09	1.31	0.202	1.97
5.84	2.01	2.23	1.74	20.27	1.30	0.198	1.93
5.78	2.03	2.25	1.75	29.70	1.86	0.282	2.80
5.72	2.03	2.27	1.73	39.94	2.40	0.368	3.64
5.66	2.03	2.28	1.72	49.51	2.90	0.440	4.38
TRIM = 6 DEG			MEAN WETTED LENGTH = 3.0 BEAMS				
5.94	3.00	3.22	2.72	5.06	0.64	0.096	1.13
5.93	3.00	3.21	2.73	10.24	0.99	0.135	1.93
5.90	3.00	3.22	2.73	20.27	1.68	0.230	3.45
5.86	3.02	3.23	2.75	29.45	2.34	0.362	4.92
5.83	3.01	3.23	2.74	40.19	3.08	0.491	6.57
5.80	3.00	3.22	2.72	50.27	3.69	0.590	7.95
TRIM = 6 DEG			MEAN WETTED LENGTH = 4.0 BEAMS				
5.96	4.06	4.27	3.79	9.98	1.33	0.167	3.13
5.98	3.97	4.19	3.70	20.09	2.12	0.322	5.51
6.00	4.00	4.20	3.74	30.08	2.95	0.467	7.93
6.02	4.01	4.21	3.76	40.19	3.81	0.616	10.47
6.04	4.05	4.26	3.78	49.13	4.56	0.742	12.70

TABLE 1 continued

τ	λ	λ_K	λ_C	C_V^2	C_Δ	C_R	C_M
TRIM = 8 DEG			MEAN WETTED LENGTH = 0.5 BEAMS				
8.01	0.53	0.70	0.31	9.71	0.41	0.067	0.19
7.97	0.48	0.64	0.27	20.00	0.82	0.116	0.35
7.97	0.53	0.70	0.31	19.40	0.84	0.122	0.39
7.88	0.52	0.68	0.30	30.08	1.27	0.177	0.64
8.11	0.52	0.68	0.31	29.70	1.29	0.205	0.58
8.01	0.53	0.68	0.32	40.44	1.76	0.261	0.79
TRIM = 8 DEG			MEAN WETTED LENGTH = 1.0 BEAMS				
7.99	0.95	1.10	0.75	9.80	0.59	0.098	0.45
7.97	0.98	1.13	0.78	19.97	1.23	0.195	0.97
7.99	0.97	1.12	0.76	30.28	1.87	0.314	1.44
7.97	0.99	1.13	0.79	40.19	2.40	0.406	1.75
7.97	0.96	1.11	0.76	50.38	3.08	0.515	2.30
TRIM = 8 DEG			MEAN WETTED LENGTH = 1.5 BEAMS				
7.97	1.50	1.64	1.30	20.00	1.59	0.218	1.77
7.48	1.51	1.68	1.29	48.80	3.42	0.526	3.89
7.66	1.59	1.74	1.39	49.37	3.73	0.601	4.47
TRIM = 8 DEG			MEAN WETTED LENGTH = 2.0 BEAMS				
7.98	2.03	2.18	1.82	10.04	0.89	0.166	1.23
7.98	1.95	2.10	1.75	19.65	1.82	0.319	2.68
7.98	2.03	2.18	1.82	29.86	2.68	0.470	4.02
8.02	2.01	2.16	1.81	39.74	3.57	0.630	5.36
7.90	1.93	2.08	1.72	50.17	4.31	0.759	6.22
TRIM = 8 DEG			MEAN WETTED LENGTH = 3.0 BEAMS				
8.01	3.02	3.18	2.81	9.93	1.30	0.213	2.58
8.01	3.01	3.16	2.80	19.65	2.32	0.407	4.86
7.98	2.98	3.12	2.79	30.17	3.36	0.605	7.13
7.94	3.01	3.16	2.80	39.76	4.34	0.777	9.34
7.99	3.00	3.15	2.80	50.06	5.45	0.988	11.79
TRIM = 8 DEG			MEAN WETTED LENGTH = 4.0 BEAMS				
7.96	4.04	4.20	3.83	10.01	1.75	0.300	4.26
7.96	4.04	4.20	3.82	19.84	2.82	0.476	7.15
8.00	4.04	4.20	3.82	20.04	2.84	0.482	7.65
7.99	4.01	4.17	3.80	19.75	2.86	0.502	7.56
8.01	4.02	4.18	3.80	29.51	4.01	0.742	10.97
8.04	4.01	4.17	3.80	39.32	5.18	0.950	14.36
7.97	4.02	4.19	3.80	50.13	6.38	1.156	17.89
7.97	4.03	4.19	3.81	49.61	6.36	1.157	17.85

TABLE 1 concluded

τ	λ	λ_K	λ_C	C_V^2	C_Δ	C_R	C_M
TRIM = 10 DEG			MEAN WETTED LENGTH = 0.5 BEAMS				
10.09	0.51	0.63	0.33	9.70	0.51	0.093	0.23
10.17	0.54	0.66	0.37	29.60	1.64	0.296	1.09
10.09	0.47	0.59	0.30	40.06	2.06	0.376	0.83
9.99	0.46	0.58	0.28	50.31	2.51	0.452	0.97
TRIM = 10 DEG			MEAN WETTED LENGTH = 1.0 BEAMS				
10.06	1.05	1.17	0.87	10.02	0.82	0.154	0.69
10.10	1.04	1.16	0.86	19.95	1.62	0.305	1.29
9.97	0.99	1.11	0.82	29.95	2.38	0.459	1.86
10.03	1.04	1.15	0.87	29.92	2.42	0.472	1.80
9.94	0.99	1.11	0.82	40.11	3.18	0.612	2.34
10.00	1.00	1.12	0.83	40.67	3.24	0.613	2.46
9.98	0.99	1.11	0.82	49.41	3.98	0.799	3.03
9.86	0.98	1.10	0.80	50.52	3.89	0.738	2.81
TRIM = 10 DEG			MEAN WETTED LENGTH = 2.0 BEAMS				
10.11	2.02	2.13	1.85	20.13	2.39	0.469	3.50
10.03	2.00	2.11	1.83	29.76	3.43	0.668	5.01
10.04	2.01	2.13	1.84	40.14	4.62	0.933	6.84
9.78	2.01	2.13	1.84	49.78	5.52	1.101	8.17
9.71	1.98	2.10	1.80	49.96	5.56	1.101	8.10
TRIM = 10 DEG			MEAN WETTED LENGTH = 3.0 BEAMS				
9.98	3.03	3.14	2.86	9.89	1.68	0.332	3.36
9.93	2.99	3.11	2.82	20.13	3.03	0.627	6.30
9.94	2.97	3.09	2.80	29.54	4.32	0.890	9.08
9.97	2.99	3.11	2.82	39.47	5.76	1.190	12.27
9.91	2.98	3.10	2.81	48.90	6.99	1.442	14.92
9.91	2.99	3.11	2.82	49.10	7.04	1.456	15.08

TABLE 2

FULL SPAN 20% FLAPS

TRIM = 4 DEG MEAN WETTED LENGTH = 2.2 BEAMS

τ	λ	λ_K	λ_C	C_V^2	C_Δ	C_R	C_H	C_M
FLAP DEFLECTIØN = 0 DEG								
4.03	2.20	2.32	1.62	20.09	0.87	0.147	0.0003	1.52
4.04	2.21	2.33	1.63	31.95	1.24	0.211	0.0003	2.13
4.01	2.23	2.35	1.65	50.62	2.00	0.349	0.0006	3.47
FLAP DEFLECTIØN = 1 DEG								
4.01	2.19	2.30	1.63	9.89	0.47	0.069	0.0004	0.72
4.03	2.20	2.30	1.64	20.00	0.86	0.137	0.0006	1.34
4.03	2.20	2.30	1.64	30.25	1.26	0.206	0.0009	1.97
4.12	2.20	2.30	1.64	49.92	2.17	0.356	0.0016	3.50
FLAP DEFLECTIØN = 2 DEG								
3.99	2.21	2.33	1.63	10.08	0.62	0.011	0.0011	0.96
3.96	2.19	2.30	1.62	19.91	0.97	0.147	0.0022	1.38
3.94	2.21	2.32	1.64	29.92	1.43	0.219	0.0034	2.08
3.91	2.21	2.34	1.63	49.92	2.33	0.370	0.0055	3.38
FLAP DEFLECTIØN = 4 DEG								
3.98	2.20	2.31	1.63	10.05	0.62	0.087	0.0022	0.79
3.91	2.19	2.31	1.62	19.74	1.17	0.179	0.0042	1.52
4.01	2.17	2.28	1.60	20.00	1.19	0.177	0.0042	1.51
3.99	2.20	2.31	1.64	30.25	1.76	0.256	0.0064	2.18
3.87	2.20	2.32	1.62	30.25	1.73	0.257	0.0064	2.22
3.79	2.19	2.31	1.61	49.92	2.78	0.418	0.0106	3.54
3.99	2.22	2.33	1.66	49.92	2.90	0.443	0.0106	3.69
FLAP DEFLECTIØN = 10 DEG								
4.01	2.23	2.34	1.67	19.91	1.79	0.281	0.0119	1.89
4.05	2.15	2.26	1.59	30.25	2.65	0.412	0.0181	2.71
3.88	2.18	2.34	1.56	49.24	4.18	0.662	0.0294	4.02
FLAP DEFLECTIØN = 15 DEG								
3.99	2.13	2.23	1.58	9.92	1.13	0.187	0.0091	1.01
3.94	2.22	2.33	1.66	20.27	2.31	0.379	0.0183	2.19
3.97	2.22	2.32	1.66	29.60	3.36	0.553	0.0273	3.01

TABLE 2 (continued)

FULL SPAN 20% FLAPS

TRIM = 6 DEG MEAN WETTED LENGTH = 2.2 BEAMS

τ	λ	λ_K	λ_C	C_V^2	C_Δ	C_R	C_H	C_M
FLAP DEFLECTIØN = 0 DEG								
5.99	2.15	2.15	1.70	20.09	1.41	0.220	0.0008	2.31
6.02	2.17	2.17	1.71	30.25	2.05	0.332	-.0001	3.39
6.07	2.22	2.21	1.77	49.92	3.38	0.556	0.0005	5.68
FLAP DEFLECTIØN = 2 DEG								
5.99	2.18	2.18	1.72	19.91	1.60	0.244	0.0028	2.49
5.99	2.18	2.18	1.72	29.60	2.27	0.355	0.0041	3.44
5.99	2.21	2.21	1.76	49.24	3.76	0.599	0.0067	5.76
FLAP DEFLECTIØN = 4 DEG								
5.96	2.22	2.22	1.76	10.05	0.97	0.135	0.0027	1.40
5.94	2.21	2.21	1.75	20.09	1.79	0.276	0.0049	2.53
5.97	2.17	2.22	1.66	29.76	2.60	0.413	0.0070	3.70
5.97	2.22	2.22	1.76	49.92	4.21	0.693	0.0116	5.90
FLAP DEFLECTIØN = 10 DEG								
6.04	2.23	2.22	1.78	9.98	1.21	0.207	0.0066	1.40
6.02	2.20	2.20	1.74	20.09	2.35	0.398	0.0127	2.75
FLAP DEFLECTIØN = 15 DEG								
6.01	2.21	2.21	1.76	10.05	1.46	0.265	0.0097	1.52
6.02	2.16	2.15	1.72	19.57	2.79	0.512	0.0189	2.87

TABLE 2 (continued)

FULL SPAN 20% FLAPS

TRIM = 8 DEG   MEAN WETTED LENGTH = 2.2 BEAMS

τ	λ	λ_K	λ_C	C_V^2	C_Δ	C_R	C_H	C_M
FLAP DEFLECTION = 0 DEG								
7.97	2.26	2.20	1.86	19.57	1.87	0.342	0.0014	3.12
7.99	2.23	2.18	1.82	29.92	2.79	0.504	0.0020	4.60
8.01	2.23	2.18	1.82	49.24	4.56	0.833	0.0030	7.55
FLAP DEFLECTION = 2 DEG								
7.97	2.19	2.13	1.79	19.74	2.02	0.377	0.0035	3.11
8.01	2.23	2.17	1.83	29.29	3.03	0.554	0.0050	4.70
8.01	2.17	2.10	1.78	48.56	4.88	0.899	0.0081	7.33
8.01	2.24	2.23	1.79	48.56	4.94	0.908	0.0082	7.48
FLAP DEFLECTION = 4 DEG								
8.02	2.18	2.11	1.79	10.17	1.19	0.216	0.0049	1.63
8.00	2.18	2.12	1.79	20.36	2.28	0.426	0.0079	3.17
7.99	2.18	2.11	1.79	30.08	3.38	0.625	0.0091	4.71
7.99	2.18	2.12	1.78	49.24	5.39	1.022	0.0141	7.49
FLAP DEFLECTION = 10 DEG								
8.12	2.22	2.16	1.83	9.98	1.54	0.296	0.0069	1.95
7.95	2.17	2.11	1.77	20.09	2.87	0.551	0.0136	3.48
FLAP DEFLECTION = 15 DEG								
7.98	2.17	2.11	1.78	10.17	1.77	0.364	0.0104	2.00
7.97	2.18	2.11	1.79	19.74	3.37	0.695	0.0199	3.77
7.97	2.14	2.08	1.74	19.91	3.31	0.691	0.0198	3.61

TABLE 2 (continued)

FULL SPAN 20% FLAPS

TRIM = 4 DEG MEAN WETTED LENGTH = 4.2 BEAMS

τ	λ	λ_K	λ_C	C_V^2	C_Δ	C_R	C_H	C_M
FLAP DEFLECTIØN = 2 DEG								
3.99	4.23	4.35	3.65	9.92	0.89	0.154	0.0002	2.01
3.99	4.17	4.29	3.60	20.27	1.43	0.250	0.0023	3.55
4.11	4.17	4.28	3.60	29.92	2.11	0.364	0.0033	5.39
4.01	4.20	4.31	3.63	50.62	3.17	0.583	0.0053	8.34
3.98	4.04	4.20	3.43	50.62	3.16	0.548	0.0054	8.03
FLAP DEFLECTIØN = 4 DEG								
3.97	4.18	4.30	3.61	9.98	1.01	0.160	0.0021	2.18
4.00	4.28	4.40	3.70	20.00	1.68	0.279	0.0044	3.92
4.01	4.12	4.25	3.54	30.08	2.29	0.392	0.0061	5.26
4.01	4.24	4.36	3.66	49.58	3.61	0.631	0.0100	8.69
FLAP DEFLECTIØN = 10 DEG								
4.02	4.16	4.28	3.58	19.91	2.25	0.358	0.0121	4.10
3.95	4.21	4.34	3.62	30.25	3.24	0.519	0.0179	6.01
4.00	4.21	4.33	3.64	49.24	5.07	0.855	0.0289	9.37
FLAP DEFLECTIØN = 15 DEG								
3.94	4.21	4.34	3.63	20.09	2.73	0.459	0.0185	4.42
4.01	4.14	4.24	3.58	29.60	3.99	0.700	0.0271	6.54
3.89	4.42	4.55	3.83	49.92	6.21	1.117	0.0451	10.16

TABLE 2 (continued)

FULL SPAN 20% FLAPS

TRIM = 6 DEG MEAN WETTED LENGTH = 4.2 BEAMS

τ	λ	λ_K	λ_C	C_V^2	C_Δ	C_R	C_H	C_M
FLAP DEFLECTION = 2 DEG								
5.99	4.25	4.25	3.80	20.09	2.17	0.398	0.0031	5.71
6.01	4.24	4.25	3.78	29.92	3.22	0.556	0.0042	8.72
6.03	4.25	4.25	3.79	50.62	5.12	0.892	0.0066	14.21
FLAP DEFLECTION = 4 DEG								
5.99	4.23	4.23	3.78	19.91	2.49	0.422	0.0050	6.10
6.01	4.20	4.20	3.74	29.92	3.46	0.593	0.0070	8.63
6.00	4.19	4.20	3.73	49.58	5.40	0.937	0.0111	13.72
FLAP DEFLECTION = 15 DEG								
5.93	4.20	4.20	3.74	19.91	3.54	0.650	0.0192	6.63
6.01	4.17	4.17	3.71	29.60	5.05	0.931	0.0282	9.45

TRIM = 8 DEG MEAN WETTED LENGTH = 4.2 BEAMS

FLAP DEFLECTION = 2 DEG								
7.96	4.22	4.16	3.83	9.86	1.96	0.350	0.0024	4.78
8.02	4.19	4.13	3.79	20.09	3.19	0.590	0.0037	8.39
8.04	4.18	4.11	3.80	29.92	4.52	0.838	0.0050	12.22
8.03	4.17	4.10	3.78	48.56	7.00	1.312	0.0077	19.30
FLAP DEFLECTION = 4 DEG								
7.97	4.20	4.14	3.81	20.09	3.40	0.610	0.0058	8.52
7.96	4.25	4.20	3.84	30.25	4.78	0.894	0.0081	12.42
8.06	4.22	4.17	3.81	48.56	7.42	1.413	0.0124	19.60
FLAP DEFLECTION = 10 DEG								
8.00	4.16	4.11	3.76	19.91	4.01	0.748	0.0138	8.81
8.02	4.17	4.11	3.78	47.91	8.69	1.710	0.0313	19.72
FLAP DEFLECTION = 15 DEG								
7.99	4.18	4.12	3.79	19.74	4.47	0.902	0.0202	9.09
8.10	4.18	4.12	3.78	29.60	6.35	1.318	0.0293	13.07

TABLE 2 (continued)

HALF SPAN 20% FLAPS

INBOARD

TRIM = 4 DEG   MEAN WETTED LENGTH = 2.10 BEAMS

τ	λ	λ_K	λ_C	C_V^2	C_Δ	C_R	C_H	C_M
FLAP DEFLECTION = 1 DEG								
4.01	2.10	2.30	1.64	10.05	0.42	0.077	0.0002	0.53
4.03	2.10	2.30	1.64	20.09	0.82	0.137	0.0004	1.14
4.03	2.10	2.30	1.64	30.08	1.24	0.202	0.0005	1.78
4.13	2.10	2.30	1.64	50.27	2.10	0.342	0.0007	3.16
FLAP DEFLECTION = 2 DEG								
4.01	2.10	2.30	1.64	9.95	0.48	0.073	0.0004	0.68
4.03	2.10	2.30	1.64	19.83	0.88	0.135	0.0008	1.25
4.01	2.10	2.30	1.64	30.08	1.36	0.206	0.0011	1.95
4.10	2.10	2.30	1.64	49.92	2.19	0.350	0.0014	3.19
FLAP DEFLECTION = 4 DEG								
4.00	2.10	2.30	1.64	9.98	0.48	0.083	0.0009	0.55
4.00	2.10	2.30	1.64	19.83	0.94	0.151	0.0016	1.17
3.99	2.10	2.30	1.64	29.92	1.40	0.220	0.0024	1.83
3.96	2.10	2.30	1.64	49.92	2.31	0.365	0.0041	3.07

OUTBOARD

TRIM = 4 DEG   MEAN WETTED LENGTH = 2.10 BEAMS

τ	λ	λ_K	λ_C	C_V^2	C_Δ	C_R	C_H	C_M
FLAP DEFLECTION = 1 DEG								
4.02	2.10	2.30	1.64	9.98	0.45	0.069	0.0001	0.65
4.04	2.10	2.30	1.64	19.91	0.83	0.131	0.0002	1.24
4.04	2.10	2.30	1.64	30.25	1.24	0.196	0.0004	1.87
4.04	2.10	2.30	1.64	50.27	2.04	0.333	0.0007	3.11
FLAP DEFLECTION = 2 DEG								
4.02	2.10	2.30	1.64	9.95	0.47	0.073	0.0004	0.67
4.03	2.10	2.30	1.64	20.18	0.86	0.139	0.0007	1.23
4.03	2.10	2.30	1.64	30.08	1.27	0.200	0.0009	1.84
4.11	2.10	2.30	1.64	49.92	2.13	0.352	0.0015	3.14
FLAP DEFLECTION = 4 DEG								
4.01	2.10	2.30	1.64	9.98	0.57	0.073	0.0008	0.84
4.01	2.10	2.30	1.64	19.91	1.00	0.139	0.0015	1.44
4.00	2.10	2.30	1.64	29.76	1.44	0.206	0.0023	2.04
3.98	2.10	2.30	1.64	50.27	2.32	0.359	0.0036	3.29

TABLE 2 (Concluded)

FULL SPAN 10% FLAPS

TRIM = 4 DEG MEAN WETTED LENGTH = 2.10 BEAMS

τ	λ	λ_K	λ_C	C_V^2	C_Δ	C_R	C_H	C_M
FLAP DEFLECTIØN = 1 DEG								
4.01	2.10	2.30	1.64	10.08	0.41	0.075	0.0000	0.50
4.03	2.10	2.30	1.64	20.00	0.82	0.143	0.0000	1.12
3.97	2.10	2.30	1.64	30.25	1.30	0.210	0.0001	1.90
4.12	2.10	2.30	1.64	49.92	2.12	0.346	0.0003	3.14
FLAP DEFLECTIØN = 2 DEG								
4.13	2.09	2.30	1.62	10.11	0.47	0.077	0.0000	1.86
3.97	2.09	2.30	1.62	19.74	0.91	0.133	0.0004	1.29
3.97	2.11	2.32	1.65	29.92	1.37	0.198	0.0006	1.99
4.05	2.12	2.33	1.65	49.24	2.21	0.347	0.0010	3.17
FLAP DEFLECTIØN = 4 DEG								
4.00	2.10	2.30	1.64	10.05	0.55	0.077	0.0003	0.70
3.99	2.10	2.30	1.64	20.09	1.06	0.161	0.0008	1.35
3.96	2.10	2.30	1.64	30.08	1.58	0.230	0.0013	2.04
4.01	2.10	2.30	1.64	49.58	2.52	0.389	0.0022	3.20

HALF SPAN INBOARD 10% FLAPS

TRIM = 4 DEG MEAN WETTED LENGTH = 2.05 BEAMS

τ	λ	λ_K	λ_C	C_V^2	C_Δ	C_R	C_H	C_M
FLAP DEFLECTIØN = 1 DEG								
4.02	2.05	2.30	1.64	9.92	0.40	0.071	0.0001	0.53
4.04	2.05	2.30	1.64	19.83	0.78	0.137	0.0001	1.11
4.04	2.05	2.30	1.64	29.76	1.19	0.188	0.0001	1.73
4.06	2.05	2.30	1.64	49.92	1.81	0.297	0.0003	2.61
FLAP DEFLECTIØN = 2 DEG								
4.02	2.05	2.30	1.64	10.08	0.46	0.071	0.0000	0.64
4.03	2.05	2.30	1.64	20.09	0.86	0.131	0.0002	1.21
4.03	2.05	2.30	1.64	30.58	1.29	0.198	0.0002	1.83
4.02	2.05	2.30	1.64	50.27	2.07	0.337	0.0003	2.96
FLAP DEFLECTIØN = 4 DEG								
4.01	2.05	2.30	1.64	9.98	0.49	0.071	0.0002	0.64
4.02	2.05	2.30	1.64	20.09	0.91	0.133	0.0002	1.19
4.01	2.05	2.30	1.64	30.08	1.33	0.200	0.0003	1.75
3.99	2.05	2.30	1.64	49.92	2.18	0.351	0.0005	2.91

TABLE 3

Average Increment in Lift, Drag, and Moment Due to Flap and Flap Hinge Moment

FULL SPAN 20% FLAPS

TRIM deg	FLAP DEFLECTION deg	ΔC_{L_b}	ΔC_{D_b}	ΔC_{M_b}	$C_{H_b} \times 10^4$
MEAN WETTED LENGTH = 2.2 BEAMS					
4	0	-.002	.0005	.012	.23
	1	.003	.0001	.009	.65
	2	.014	-.0009	.014	2.23
	4	.033	.0017	.020	4.25
	10	.091	.0079	.046	11.95
	15	.142	.0141	.078	18.30
6	0	.004	.0006	.020	.24
	2	.022	.0010	.029	2.77
	4	.040	.0023	.037	4.77
	10	.092	.0071	.060	12.83
	15	.143	.0148	.081	19.35
8	0	-.002	-.0003	.015	1.29
	2	.016	.0011	.016	3.40
	4	.032	.0024	.014	6.56
	10	.090	.0068	.055	13.60
	15	.139	.0154	.075	20.13
MEAN WETTED LENGTH = 4.2 BEAMS					
4	2	.011	.0010	-.003	2.05
	4	.029	.0022	.017	4.13
	10	.090	.0071	.050	11.84
	15	.137	.0148	.081	18.21
6	2	.007	.0004	.008	2.76
	4	.026	.0014	.012	4.65
	15	.134	.0142	.074	19.16
8	2	.005	-.0011	.009	3.47
	4	.022	-.0004	.017	5.32
	10	.084	.0060	.043	13.31
	15	.130	.0136	.076	20.09

TABLE 3 (Concluded)

FLAP DEFLECTION deg	ΔC_{L_b}	ΔC_{D_b}	ΔC_{M_b}	$C_{H_b} \times 10^4$
HALF SPAN 20% FLAPS TRIM = 4° MEAN WETTED LENGTH = 2.1 BEAMS				
INBOARD				
1	.002	.0002	.001	.33
2	.008	.0002	.010	.68
4	.012	.0008	.002	1.63
OUTBOARD				
1	.001	-.0002	.005	.26
2	.005	.0001	.006	.63
4	.016	-.0001	.019	1.48
FULL SPAN 10% FLAPS TRIM = 4° MEAN WETTED LENGTH = 2.1 BEAMS				
1	.003	.0006	.002	.09
2	.010	.0002	.034	.38
4	.023	.0014	.014	.84
HALF SPAN 10% INBOARD FLAPS TRIM = 4° MEAN WETTED LENGTH = 2.05 BEAMS				
1	-.004	-.0004	-.006	.09
2	.004	.0002	.005	.12
4	.009	.0004	.003	.23

Fig. 1a Unflapped Model

Fig. 1b Flaps and Flap Balance

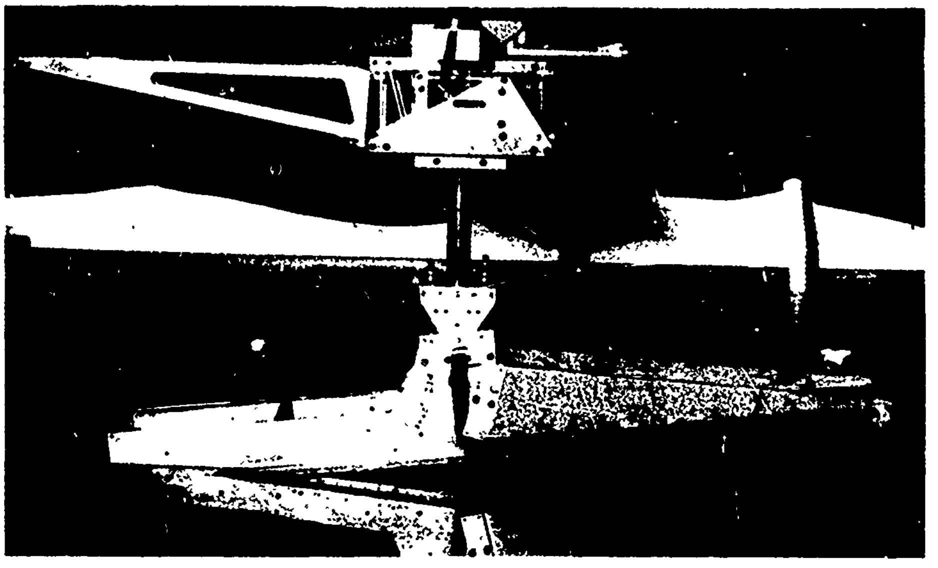

Fig. 2a Force and Moment Balance

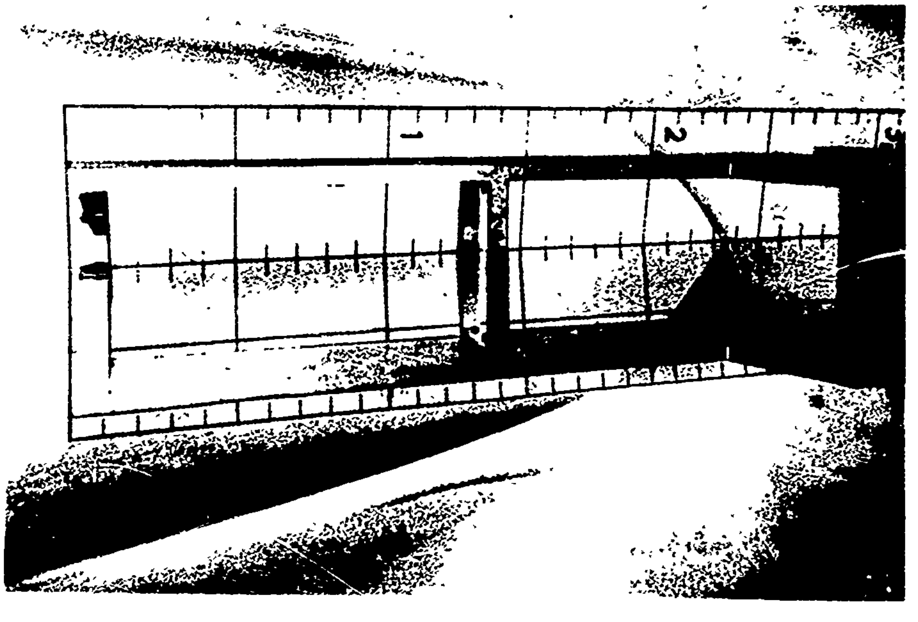

Fig. 2b Typical Wetted Area Photograph

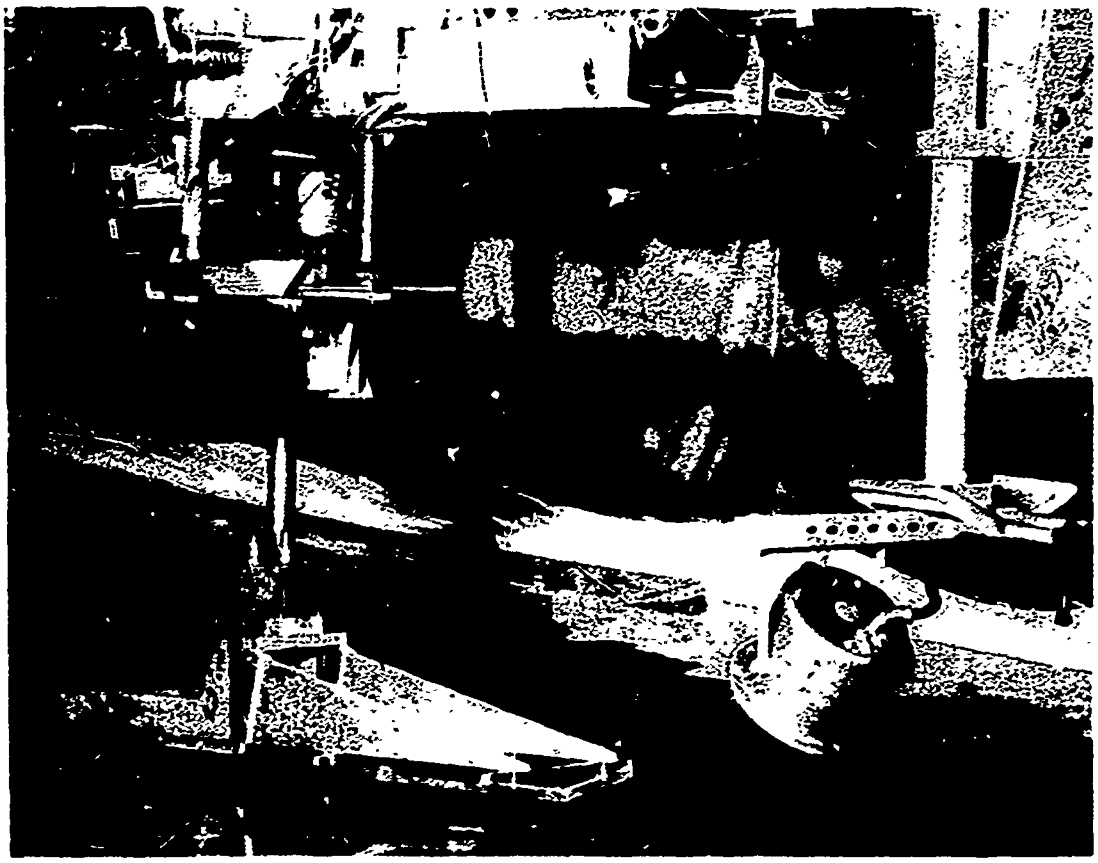

Fig. 3 Test Setup

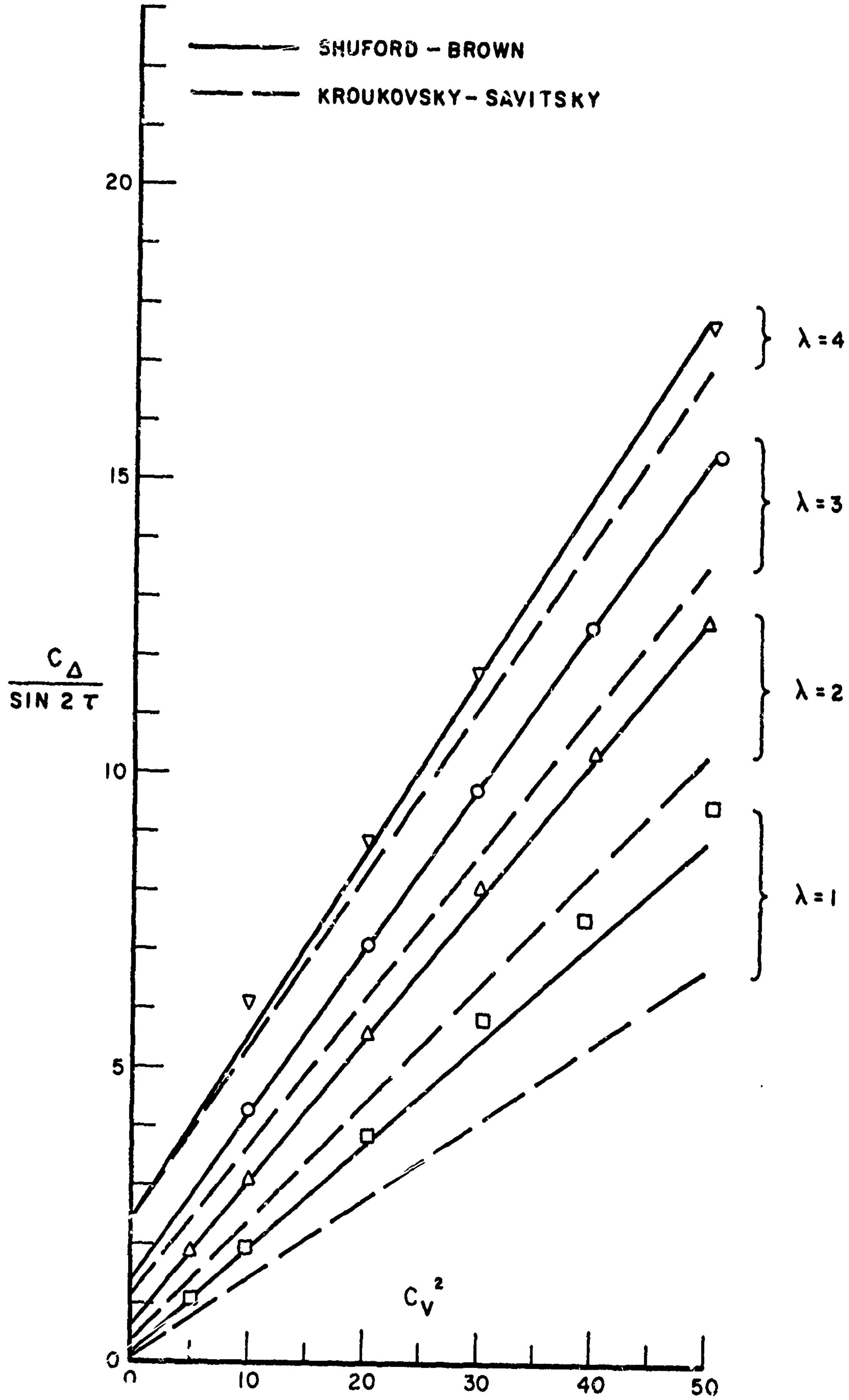

FIG. 4. LIFT AT 2° TRIM

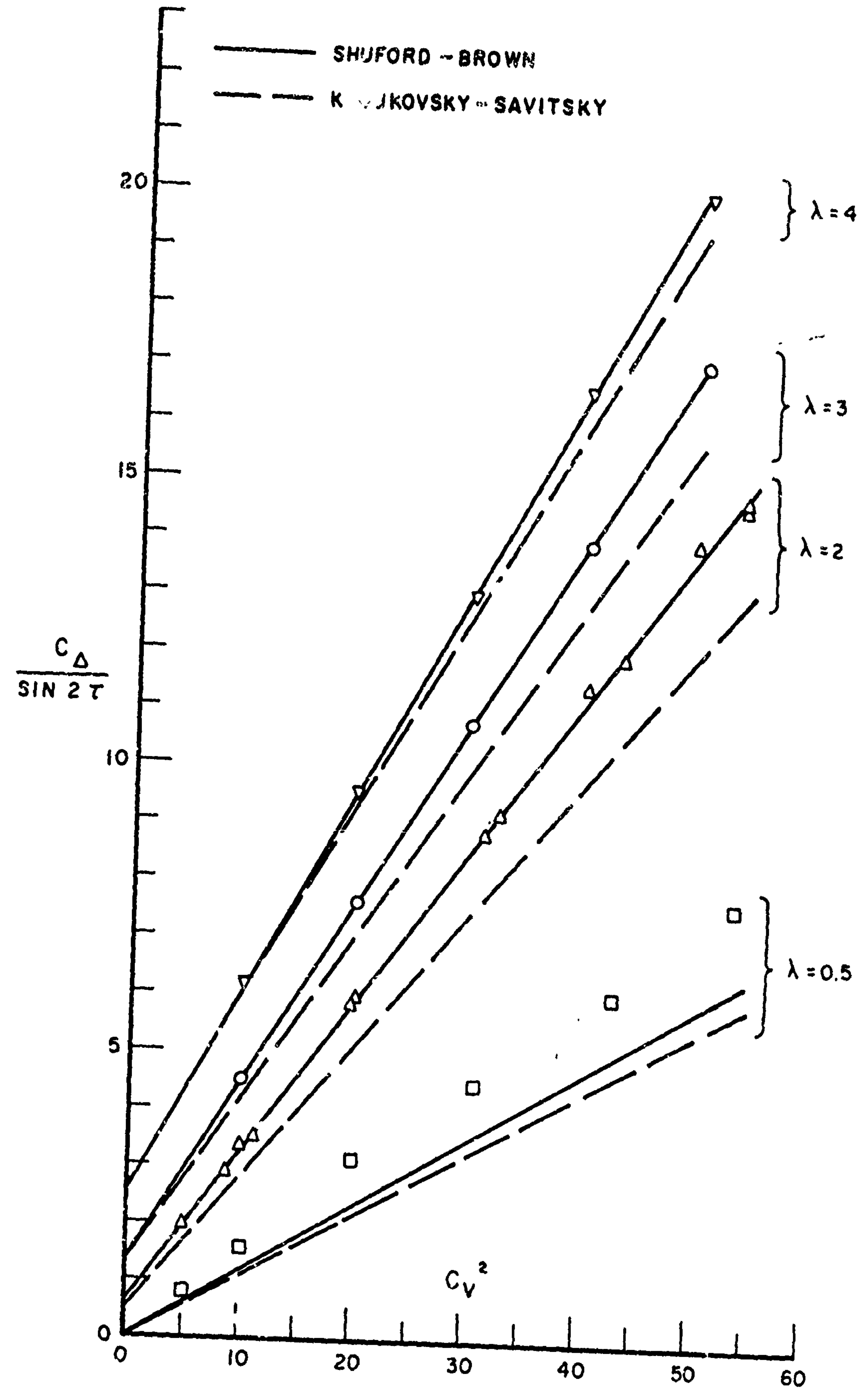

FIG. 5. LIFT AT 4° TRIM

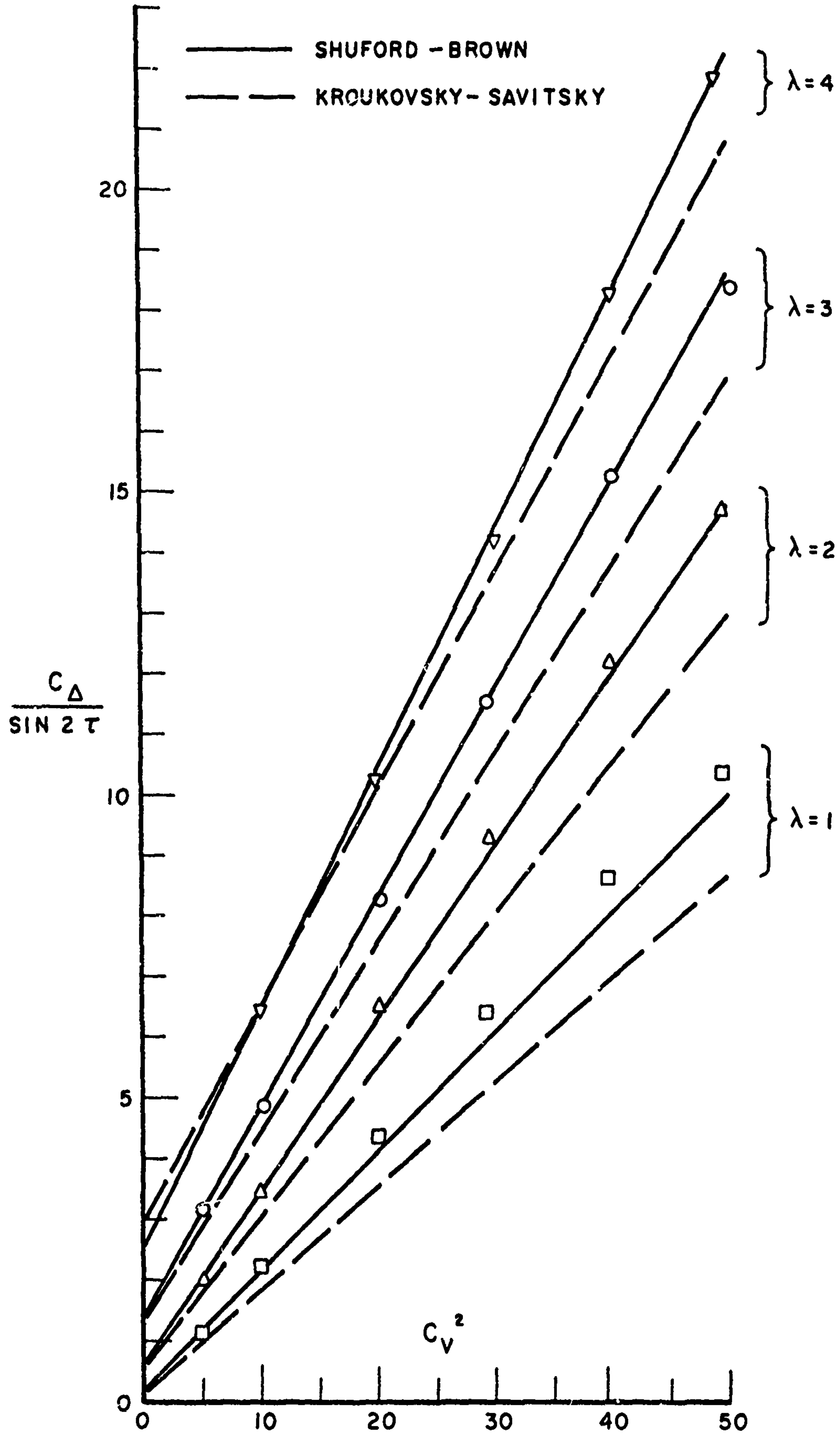

FIG. 6. LIFT AT 6° TRIM

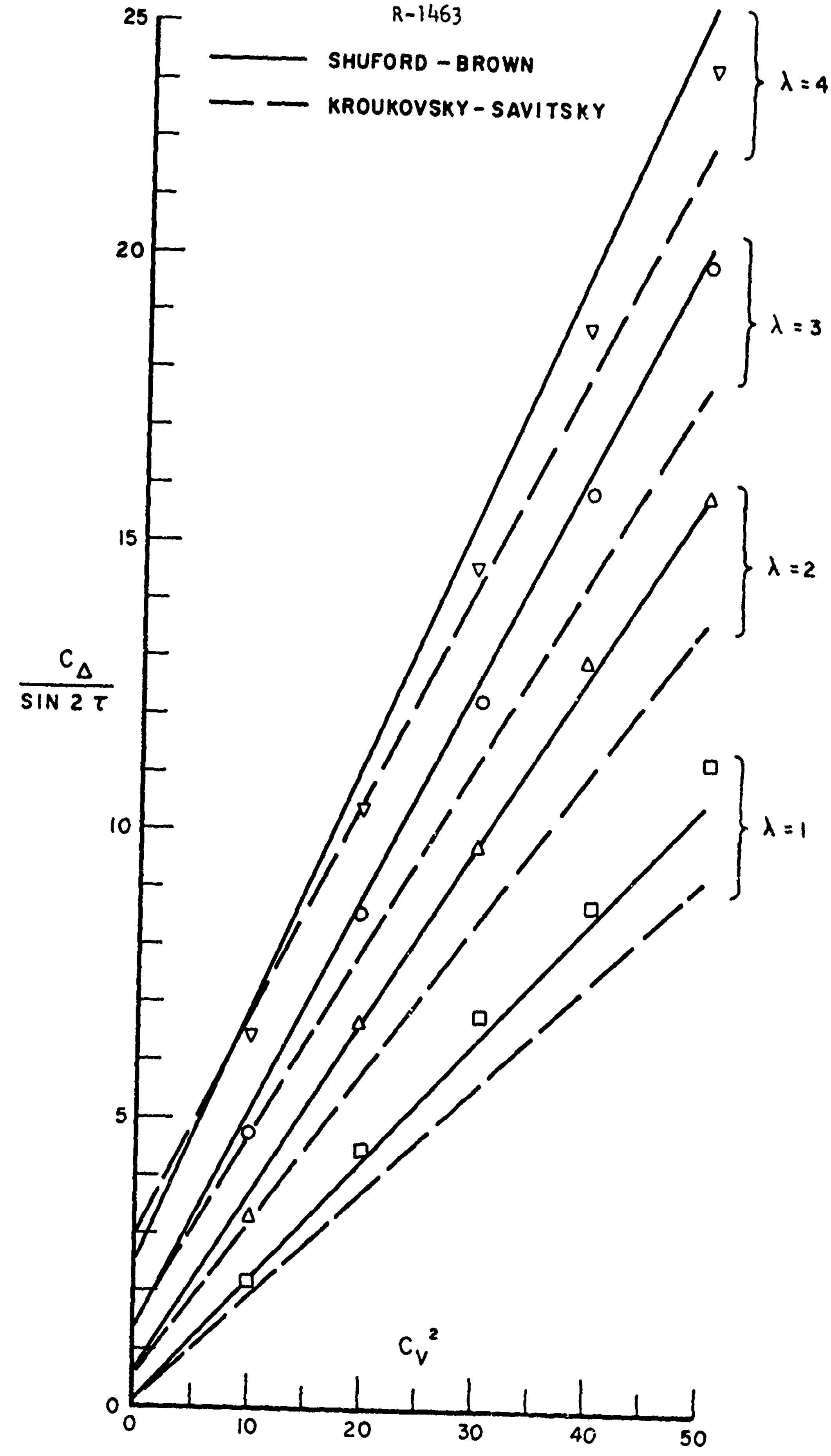

FIG. 7. LIFT AT 8° TRIM

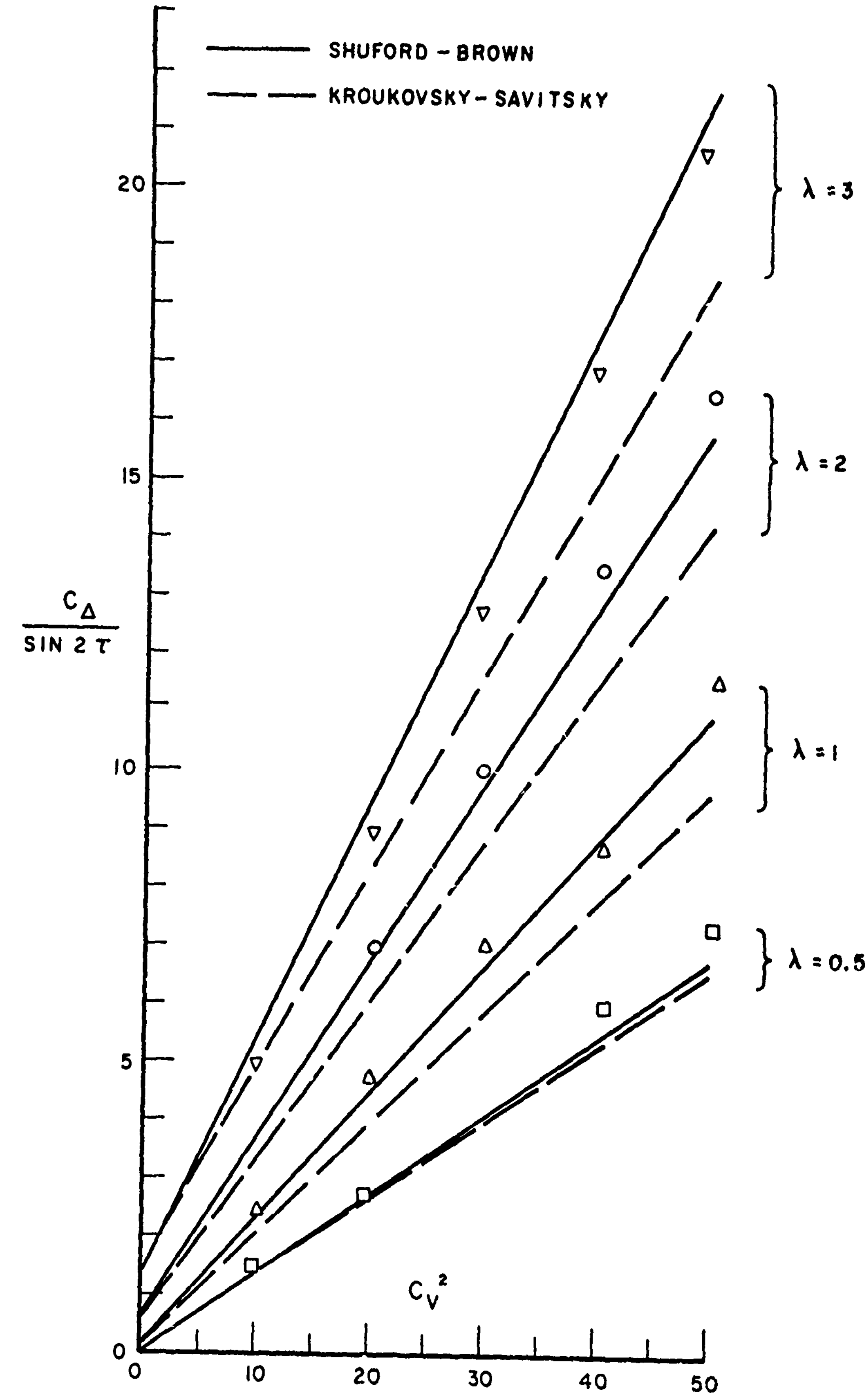

FIG. 8. LIFT AT 10° TRIM

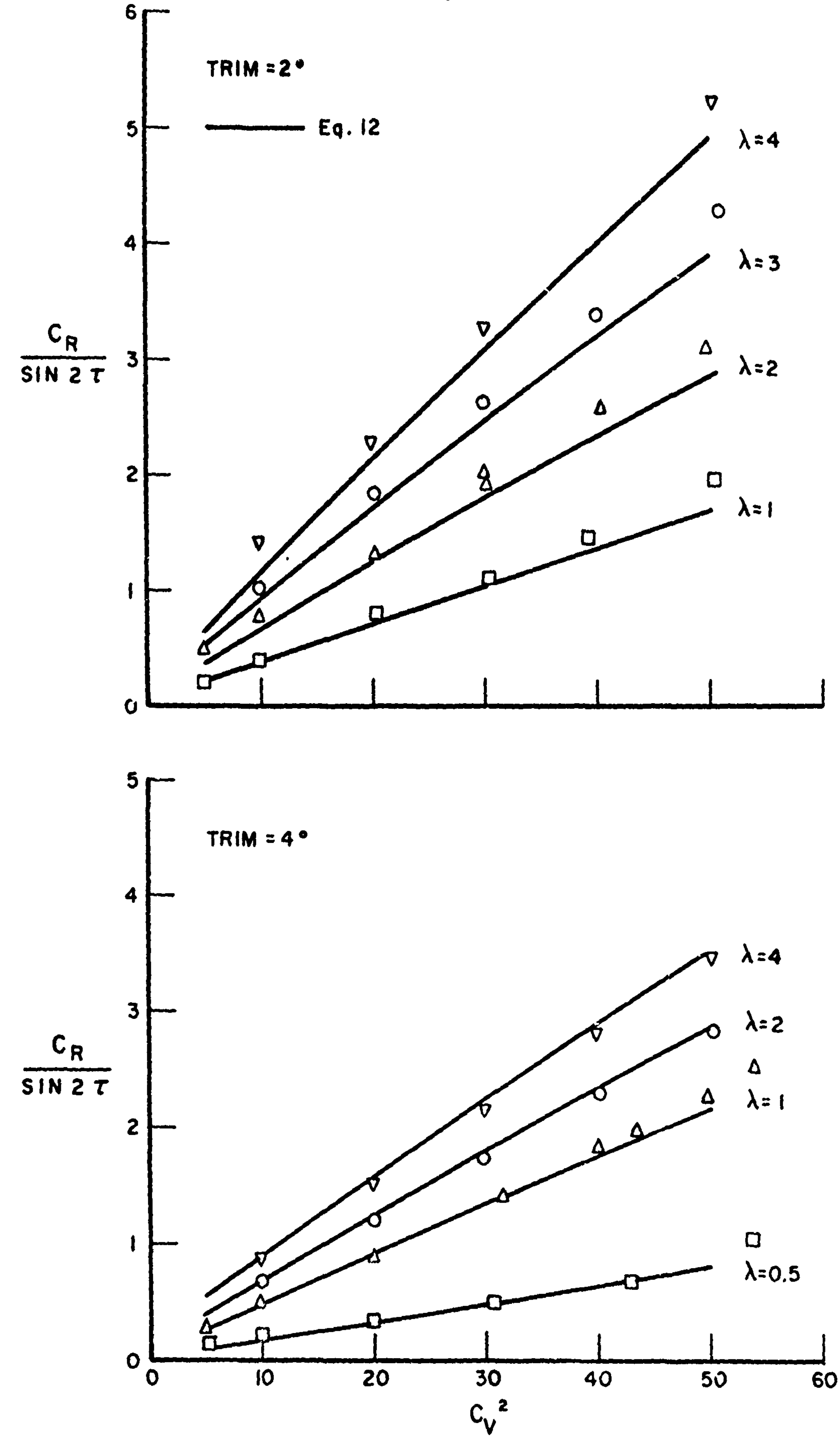

FIG. 9. DRAG AT 2° & 4° TRIM

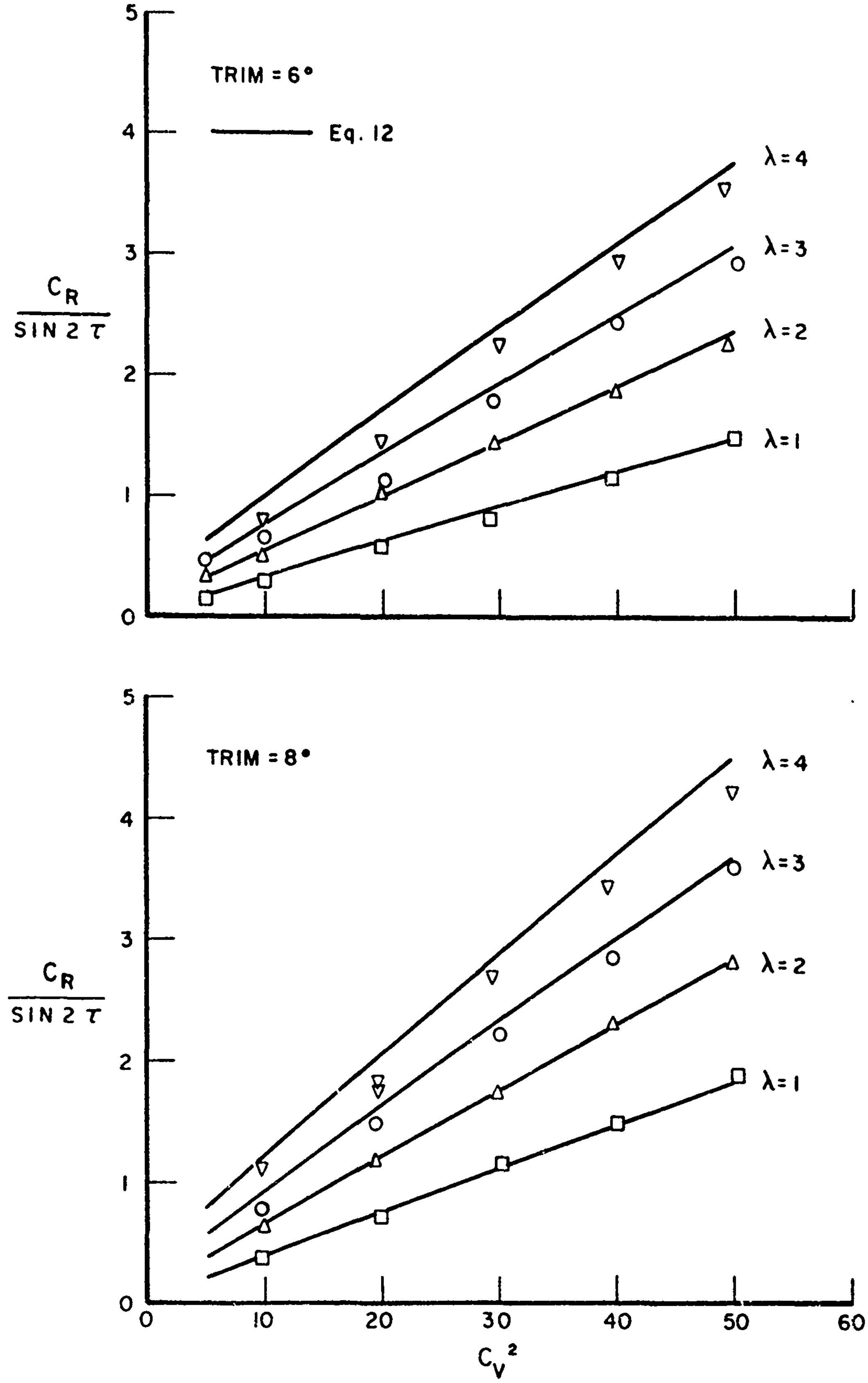

FIG. 10. DRAG AT 6° & 8° TRIM

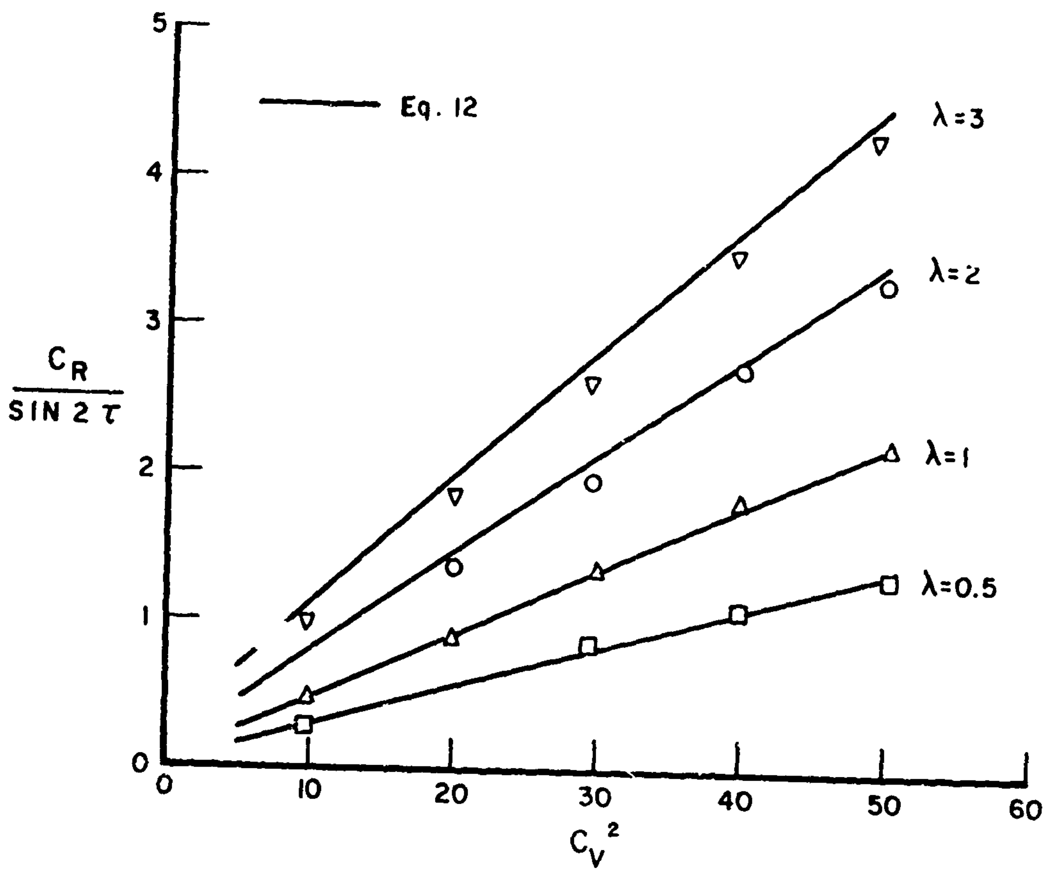

FIG. 11. DRAG AT 10° TRIM

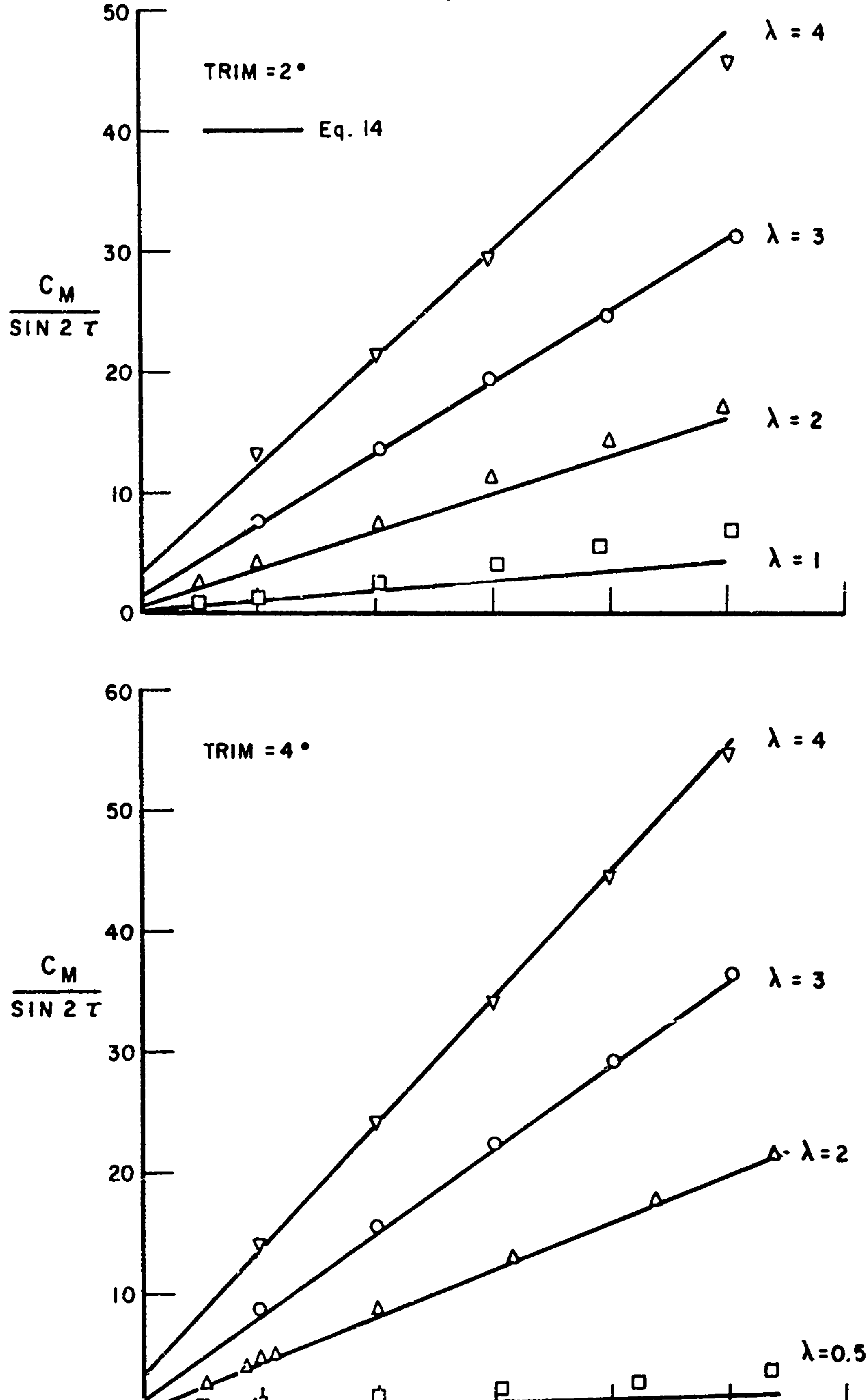

FIG. 12. MOMENT AT 2° & 4° TRIM

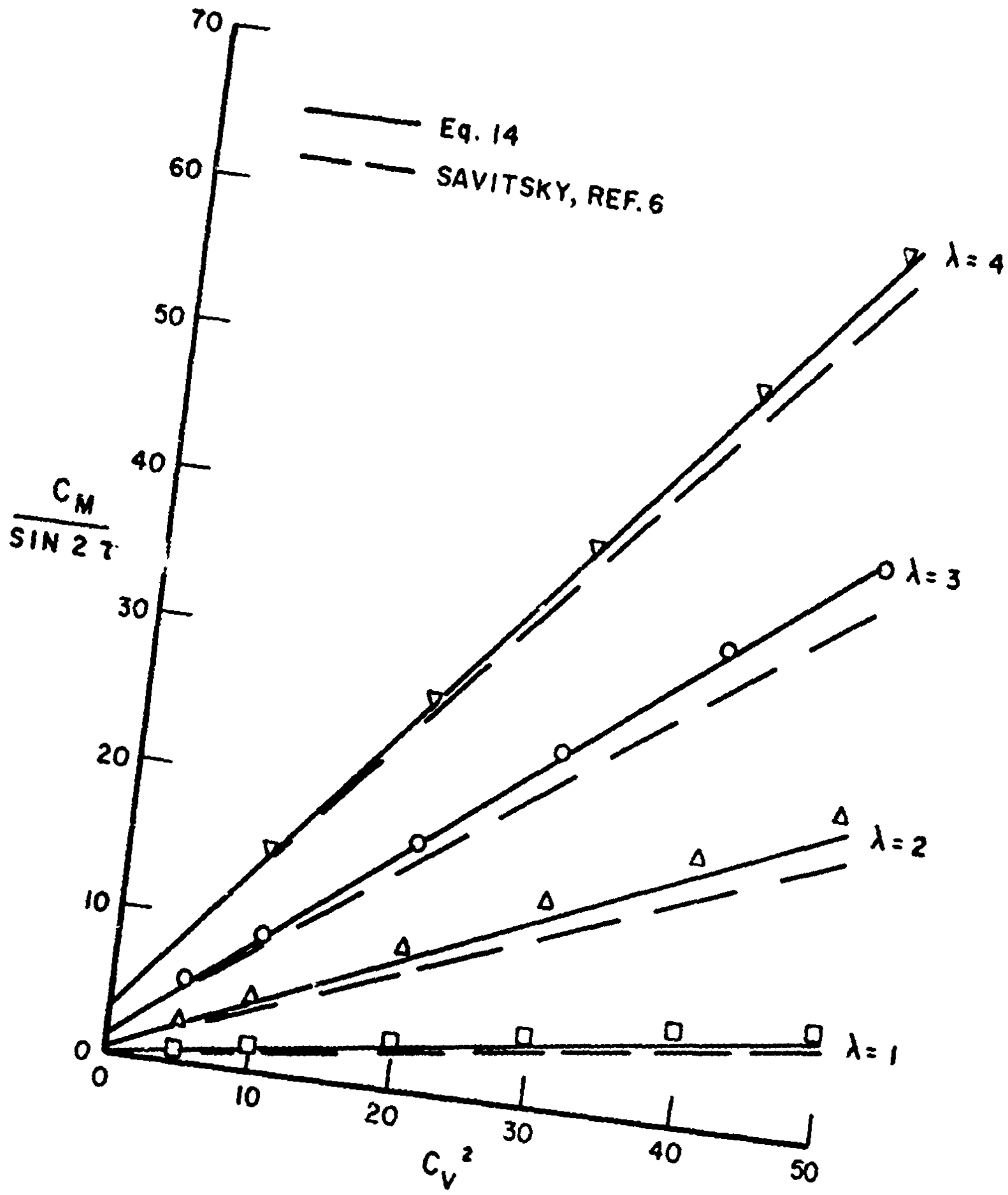

FIG. 13. MOMENT AT 6° TRIM

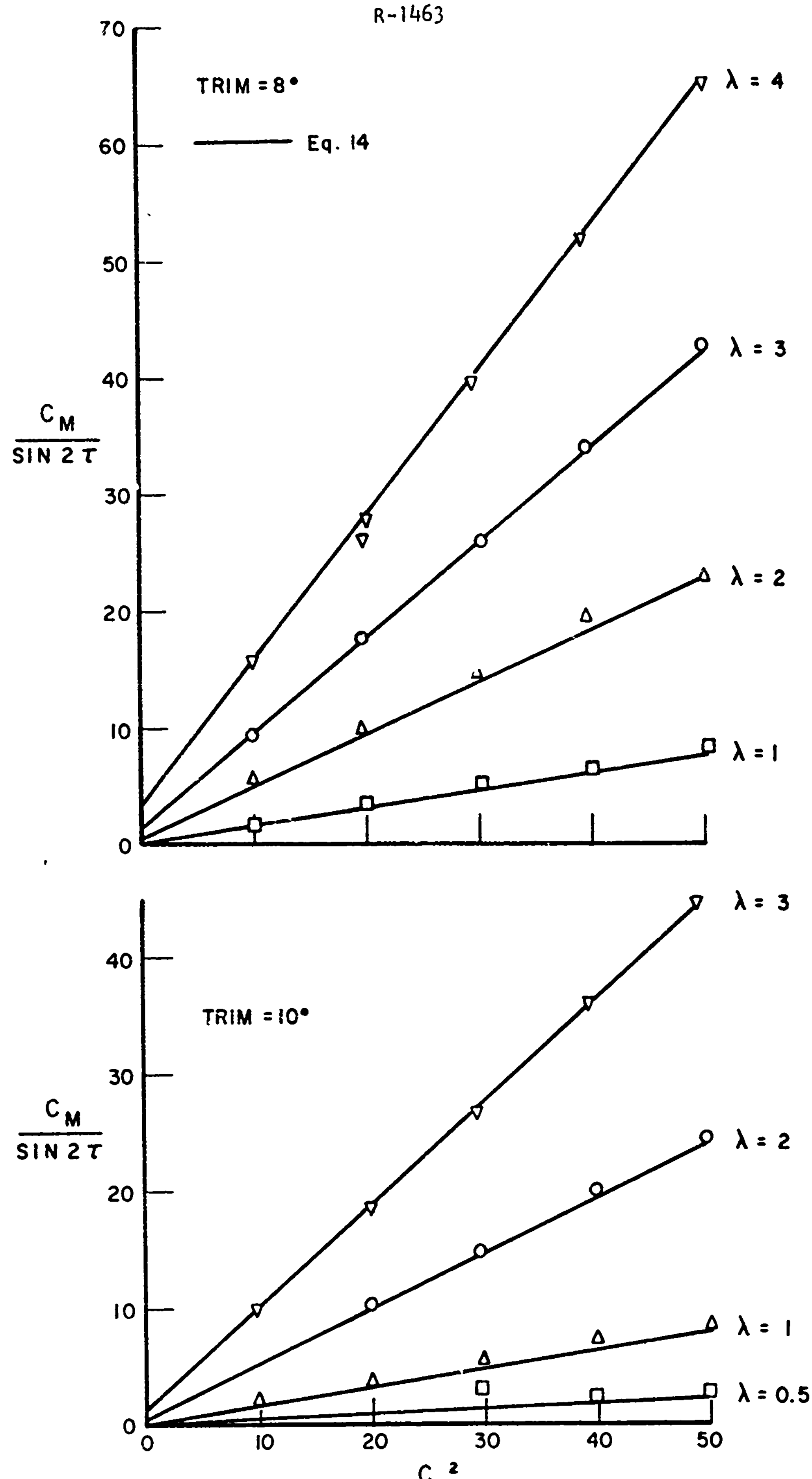

FIG. 14. MOMENT AT 8° & 10° TRIM

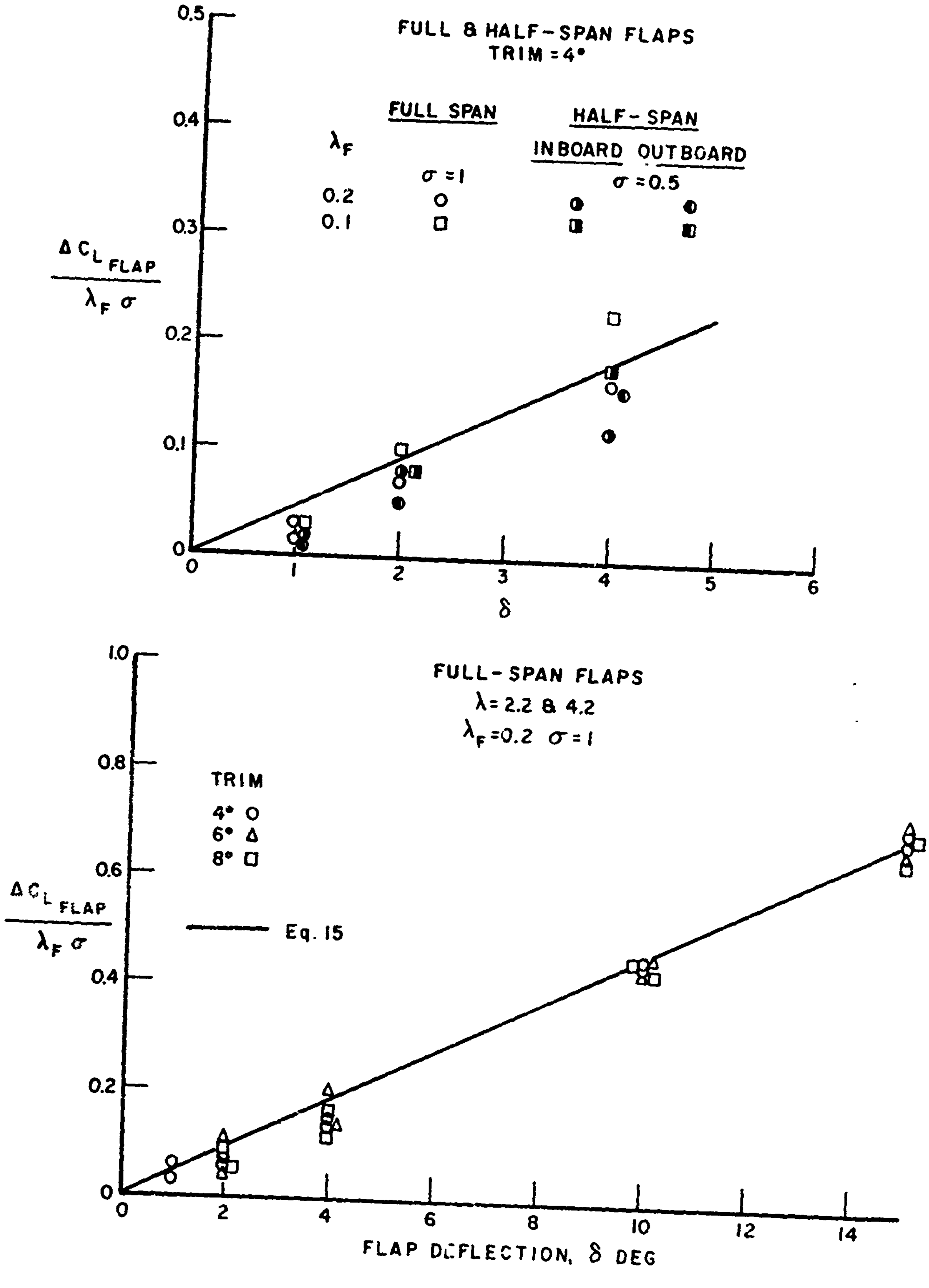

FIG. 15. ADDED LIFT DUE TO FLAP

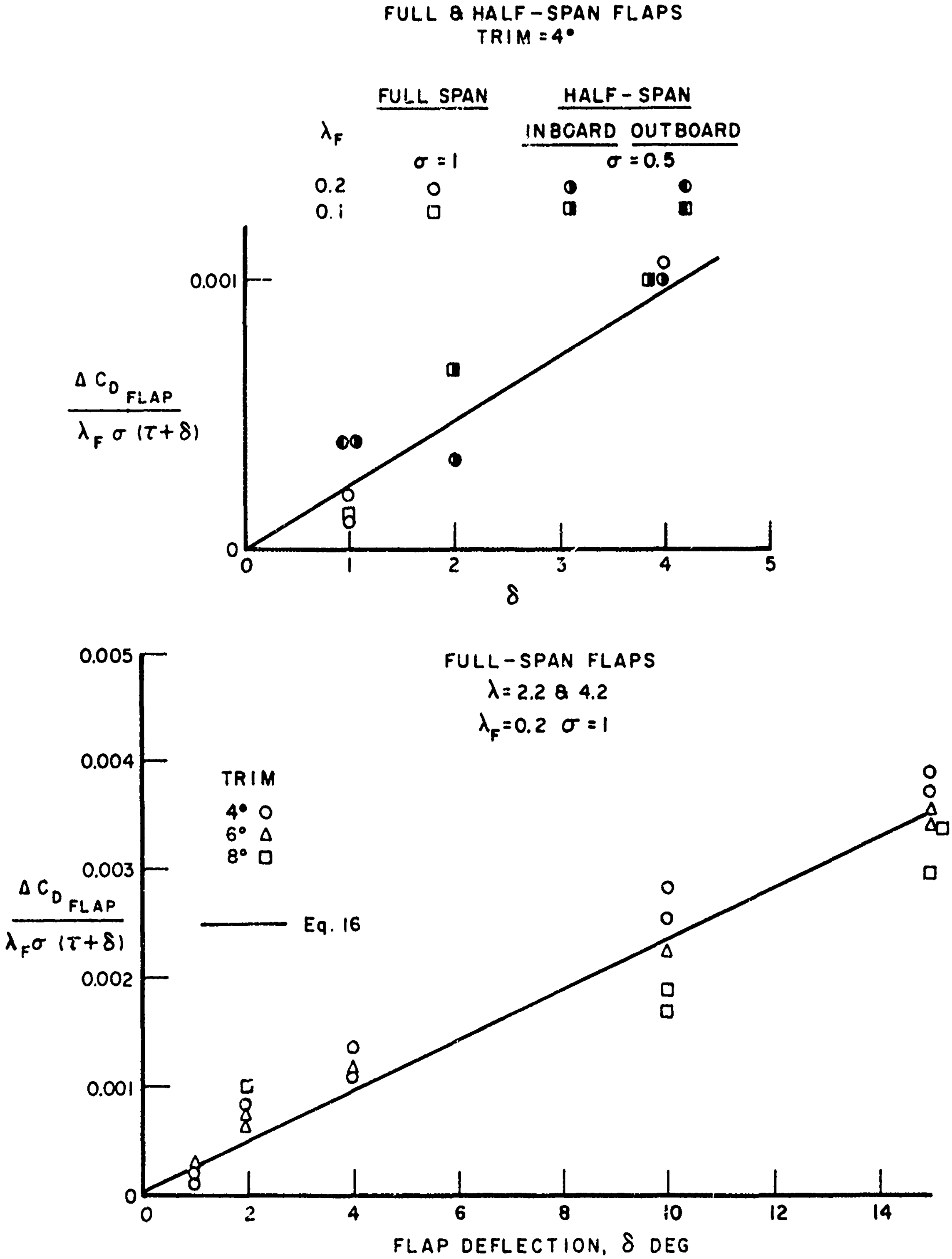

FIG. 16. ADDED DRAG DUE TO FLAP

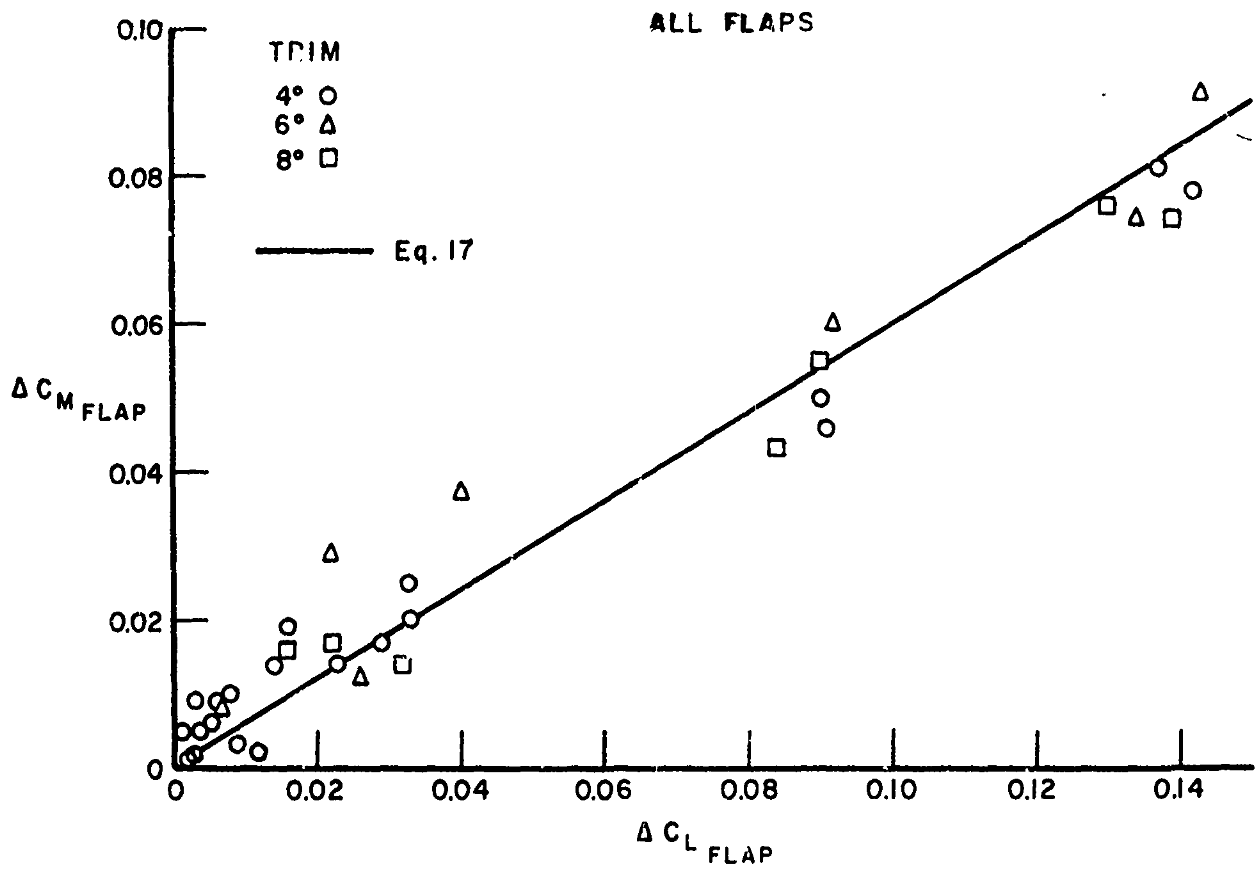

FIG. 17. ADDED MOMENT DUE TO FLAP

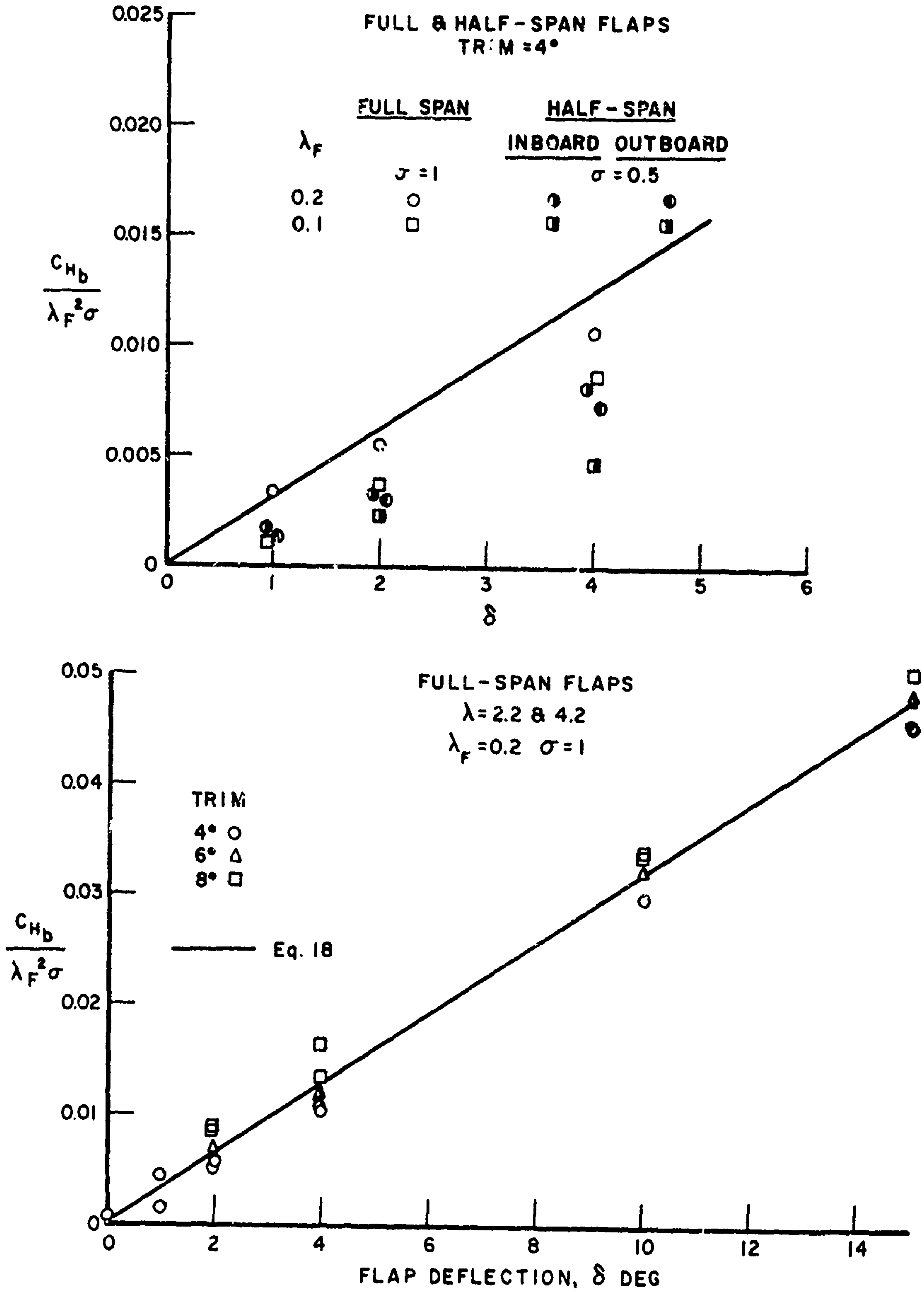

FIG. 18. HINGE MOMENT PER FLAP

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13. ABSTRACT

Experiments were made on a 10° deadrise prismatic planing surface over a range of speed both with and without full span and half span trim flaps fitted at the transom. The lift, drag and pitching moment characteristics are summarized in planing formulae which account for the effect of transom flaps and include the flap hinge moments.

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p. 4 The equation in the second paragraph should have a plus sign added so as to read

$$\lambda = 0.5(\lambda_K + \lambda_C) + 0.03 + \lambda_F \sigma$$