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COMPUTATION OF SPANWISE DISTRIBUTION OF CIRCULATION AND LIFT COEFFICIENT FOR FLAPPED WINGS OF ARBITRARY PLANFORM

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INTRODUCTION

Wing tip vortices have long been discussed as a primary factor in determining the distribution pattern and swath widths of materials ejected from agricultural aircraft. Some analytic work has been conducted to determine the effect of span loading on distribution pattern, starting with Wilmer Reed in 1954. (NACA TR #1196, 1953). Thousands of distribution patterns have been measured by researchers and many attempts have been made to modify the pattern of wing tip vortices but none of this work has provided a basis for altering either agricultural airplane design or agricultural airplane operations.

A quantitative assessment of the effect of span loading, both in magnitude and pattern, suitable for use in the field or by aircraft designers or modifiers appears to be necessary to permit decisions to be made with regard to airplane geometric characteristics or airplane flight operations. The advent of programmable calculators and microprocessor computers makes it possible to perform calculations which, up to this time, have been either difficult or impossible because of complexity and length. Accordingly the procedure for calculating span wise load distribution as described in NACA Technical Report 1071 has been programmed on a programmable calculator, the Hewlett Packard HP-97, as well as in BASIC Lanugage. The HP-97 and microprocessors which use BASIC Language are readily available and these programs will make it possible for either an airplane designer or airplane operator to study the effects of span loading on either design or operation.

The procedure of computing a span loading as given in NACA Technical Report 1071 has been reduced to a series of tables and charts so that the user need only to insert the geometric characteristics of his wings, together with the operating specifications of his airplane, and a span loading for his particular wing can be developed. The use of these programs, in conjunction with ASAE Paper #AA 79-001 will enable operators and designers to explore design and operating parameters to determine whether changes or modifications are possible that would materially or economically effect the swath width and distribution pattern.

SYMBOLS

A	aspect ratio $\frac{b^2}{S}$
b	span of the wing measured perpendicular to the plane of symmetry, feet
c	wing chord, feet
c_{av}	mean wing chord $\frac{S}{b}$, feet
c_l	local lift coefficient $\frac{\text{local lift}}{qc}$
C_L	lift coefficient $\frac{\text{total lift}}{qS}$
C_{L_δ}	rate of change of lift coefficient with flap deflection, per radian
C_{L_α}	rate of change of lift coefficient with wing angle of attack, per radian
$\frac{c_l c}{C_L c_{av}}$	spanwise loading coefficient for unit lift coefficient $\frac{2AG}{C_L}$
G	spanwise loading coefficient or dimensionless circulation $\frac{c_l c}{2b}$ or $\frac{\Gamma}{bV}$

SYMBOLS

G	spanwise loading coefficient per radian of flap deflection $\frac{G}{\delta_1}$
M	Mach number
m	arbitrary number of span stations
q	free-stream dynamic pressure, pounds per square foot
S	wing area, square feet
V	free-stream velocity, feet per second
W	airplane weight, lb
W/S	Wing loading, lb/ft^2
w	induced velocity, normal to the lifting surface positive for downwash, feet per second
x	longitudinal coordinate measured from the lateral plane through the quarter chord of the wing-root chord, feet
y	lateral coordinate measured from the wing-root perpendicular to the plane of symmetry, feet
α	wing angle of attack, radians

SYMBOLS

α_ν	section angle of attack at span station ν, radians
$\frac{d\alpha}{d\delta}$	lift-effectiveness parameter $\frac{C_{L_\delta}}{C_{L_\alpha}}$
β	compressibility parameter $\sqrt{1 - M^2}$
Γ	circulation, feet squared per second
δ	angle of deflection of flap. radians
η	dimensionless lateral coordinate $\frac{y}{b/2}$
η_f	dimensionless flap span on one wing panel, measured perpendicular to the plane of symmetry, from the wing root outboard for inboard flaps, and from the wing tip inboard for outboard flaps $\frac{\text{flap span}}{b/2}$
ρ	air density slugs/ft^3
k_ν	ratio of section lift-curve slope at span station ν to $\frac{2\pi}{\beta}$, both at the same Mach number
Λ_β	sweep angle of the wing quarter-chord line, positive for sweepback, degrees
λ	wing taper ratio $\frac{\text{tip chord}}{\text{root chord}}$

SYMBOLS

SUBSCRIPTS

f	pertaining to flaps
t	wing tip,
r	wing root
av	average or mean
1	denoting full wing-chord flaps $\frac{c_f}{c} = 1$
ν	pertaining to spanwise station

CONVERSION FACTORS

1 meter (M)	=	3.281 feet
1 sq. meter (M^2)	=	10.76 sq. feet
1 meter/sec.(M/sec.)	=	3.281 ft./sec.
1 meters/sec.^{2}(M/sec^2)	=	3.281 ft./sec.
1 Kilogram (Kg)	=	2.205 pounds
1 Kg/M^3	=	.2048 slugs/ft.^{3}
1 Newton/M^2	=	2.089×10^{-2} lb./ft.^{2}

COMPUTATION PROCEDURE

No attempt will be made to summarize the theory or analysis which is the base for computing a span load distribution as per NACA Technical Report No. 1071. Rather, a step-by-step procedure will be tabulated, which procedure has been programmed for machine calculation.

A. The first step is to determine a span loading coefficient, $G = \frac{c_1 \cdot c}{2b}$. This is a dimensionless factor which is specified per radian angle of attack (or flap deflection angle of one radian). This coefficient is also written as $\frac{G}{\delta_1} = \frac{\Gamma}{2b}$, from which it can be seen that:

$$\frac{c_1 \cdot c}{2b} = \frac{\Gamma}{bV}$$

$$\text{or } \Gamma = \frac{c_1 \cdot c}{2}$$

The value of G/δ_1 varies with span and is a function of wing aspect ratio, taper ratio, sweep and flap span. It can be computed from the simultaneous equations (4) of Technical Report No. 1071 but it has already been computed and plotted in Figure 4 of T.R. 1071 for a range of aspect ratios, sweep, taper ratios, and flap span. Two of these curves, Figures 4(c) and 4(d), for sweep angles of 0°, have been used to read values of G/δ_1 for aspect ratios of 6, 8, and 10; taper ratios of .667 and 1.0; and flap spans of .195b, .556b, and 1.0b. These graphs appear as Figure 1 and Figure 2 of this report. G/δ_1 values were also read for outboard flap spans of .444b and .805b which are the complements of .195 and .556. These values are tabulated in Table I through Table V.

The first step in the computational procedure is therefore to read from Table I through Table V the appropriate values of G/δ_1 for the selected wing and flap span at each of the span stations.

B. The wing specifications of span, taper ratio, wing area, and section lift curve slope must be defined.

C. The wing or airplane operating conditions of wing loading, air density and speed, in proper units, must be stated.

D. Agricultural aircraft all operate at maximum airspeed less than 300 ft./ sec. No correction for Mach Number is therefore required.

E. The wing chord at the spanwise stations corresponding to values of G/δ_1 must be computed. For a given taper ratio , λ , the expressions for root and tip chord are:

$$c_r = \frac{2 \cdot S}{b\ (1+\lambda)}$$

$$c_t = \lambda \cdot c_r$$

The wing chord at any spanwise station, $\frac{y}{b/2}$, is:

$$c_y = c_r \left\{ 1 - \left[\frac{y}{b/2} (1-\lambda) \right] \right\}$$

F. Since $G/\delta_1 = \frac{c_1 \cdot c}{2b}$,

$$c_1 \cdot c = 2b\ (G/\delta_1)$$

$c_1 \cdot c$ is computed and the wing lift coefficient at station y is : $c_{1_y} = \frac{c_1 \cdot c}{c_y}$

G. If a wing operating lift coefficient is chosen, the flight speed is:

$$V = \sqrt{\frac{W/S}{(\rho/2)\ V^2}}$$

or

$$C_L = \frac{W/S}{(\rho/2)\ V^2}$$

H. The circulation, Γ, at each span station is:

$$\Gamma_y = \frac{c_{l_y}\ (\rho/2)\ S_y \cdot V^2}{\rho V} = \frac{c_{l_y} \cdot S_y \cdot V}{2}$$

and

$$\Gamma_y = \frac{c_{l_y} \cdot c_y \cdot \Delta_y \cdot V}{2}$$

A plot of Γ_y as a function of span will enable $\Delta\Gamma/\Delta y$ to be secured. In order to compare this value of shed vorticity with another wing, both values of must be computed at the same wing C_L.

I. The wing lift coefficient for α = 1 radian is computed as follows:

$$C_{L_1} = \frac{\sum \left(c_{l_y} \cdot c_y \cdot \Delta y\right)}{S}$$

The wing lift coefficient at any angle of attack is:

$$C_L = \frac{C_{L_1}}{57.3} \cdot \alpha$$

The section lift coefficient at any spanwise station for a given operating lift coefficient, $C_{L_{op}}$ is:

$$c_{l_{y_{op}}} = \frac{c_{l_{y_1}} \cdot c_{l_{op}}}{C_{L_1}}$$

J. Wing lift curve slope is:

$$\frac{dC_L}{d\alpha} = \frac{C_{L_1}}{57.3}$$

K. The local lift coefficient, c_y, at any span station ,y, is given by:

$$c_{l_y} = \frac{C_L \cdot c_{l_y}}{C_{L_1}}$$

H.P. 97 Program.

The Hewlett-Packard H.P. 97 programmable calculator is a small desk size unit which is programmed in its own machine language. 224 program steps are available with 26 storage registers. Programs are stored on small magnetic cards.

The Span loading analysis program is listed on pages 28 and 29 . Data entry instructions and program operating instructions are given in appendix A.

The program is run in two segments using the computation forms shown on pages 26 and 27 .

The first segment of the program computes the local wing chord at station y, ranging from root to tip, at span stations as identified from the appropriate Table I through V. The wing characteristics are summarized on the first computation page, following which G/δ_1 and y/b/2 values are listed in the first two columns. The value of Δy is the length of each span segment, entered in feet. Successive computations are performed to secure the chord length at the midpoint of each span segment. The output of the computer is illustrated on page 30 . The computed values of C_y are entered in column 5.

The second segment of the program uses computational chart II with the entries as shown on page 31 . The first run is an initializing run followed by sequence computation of circulation at each span station. A sample computer listing with indentifier code is shown on page 30 .

BASIC PROGRAM

The span loading analysis procedure has been programmed in BASIC language for a Rockwell AIM-65 microprocessor. This program should be adaptable to any of the currently available microprocessors although it should be carefully studied to see whether the syntax of this program is compatible with the microprocessor in question.

The parameters which describe the particular wing being studies, such as gross weight, wing area, lift coefficient (corresponding to the desired swath speed), air density, taper ratio, aspect ratio, flap span, and so forth, are entered manually into the program as per the program statements. If the value of X in statement 16 is input as zero the program computes the swath speed and lists this speed. Alternatively a value of 1.0 for X in statement 16 will cause the program to compute a flight lift coefficient based upon an input speed. In other words, a choice can be made of either selecting an operating lift coefficient and the speed will be computed and printed out or the swath speed can be input and the operating lift coefficient will be computed and printed out.

A twenty column listing gives sequential values of lift coefficient and circulation as a function of span position. Final output is the lift coefficient per radian for either angle of attack or flap deflection together with the lift curve slope of the particular wing. Additional wing geometries can be explored without changing airplane parameters by entering the wing geometry parameters in data statements 170, 171, 172, and 173. The numbers in these data statements are concurrent values of the span station and G/δ_1 factor. For the program as illustrated in Appendix B the first two numbers in statement 170 are actual illustrations of the G/δ_1 factor of .379 at a span station of .05. The numbers as actually illustrated in the listed program correspond to values for a wing with full span flaps, aspect ratio 8 and a taper ratio of .667. These values were taken from Table III. In summary, data statements 170 thru 173 are the tabular values of the span loading factor as read from table I-V.

The output of the BASIC program is a function of the printer being used with the microprocessor. A twenty column output listing is illustrated on page 34 (Appendix B).

Two versions of the BASIC span loading program were prepared. These are designated with file names of SPNLA and SPNLB respectively. They differ only in the manner in which variables are entered into the computer.

In SPNLA the airplane and operating parameters are written as program statements 17 through 24. This version of the program is useful when a large number of wings are to be compared for the same airplane parameters.

In SPNLB the airplane and operating parameters are entered as input statements 17 through 24. With this version of the BASIC program every variable must be entered each time the program is run but SPNLB gives more flexibility in parameter variation.

The output listing of both SPNLA and SPNLB are the same except for listing of input data. A sample output listing is shown on page 36.

WING ANALYSIS

A large number of wings, with parameters as tabulated in Tables VI, VII, and VIII, pages 21 thru 23,have been analyzed. Span loading curves for these wings have been prepared and are presented in Figures 3&4. These curves, or the listing from computer programs, can be used to compare span loadings for various wings at various operating conditions.

CONCLUDING REMARKS

Two programs, one for a programmable calculator and one written in BASIC for a microprocessor have been prepared to compute span loading analysis for wings of varying parameters. The span loading as computed by the procedures in this report can be used, in conjunction with reference 4 to evaluate the effect of span loading and its distribution upon the trajectory of particles discharged from any point along the wing span. By using the shed vorticity, as determined by the method as described in this report in conjunction with the dynamics of the discharge particles, a prediction of distribution pattern is possible.

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Table I
Values of span loading factor G/δ_1
from reference 3 for wings with
inboard flaps, η_f =.195 b/2

TAPER RATIO=.667

STATION, $\%^b/2$	ASPECT RATIO=6	ASPECT RATIO=8	ASPECT RATIO=10
.05	.26	.235	.21
.15	.225	.20	.175
.25	.14	.115	.09
.35	.085	.068	.05
.45	.06	.045	.03
.55	.035	.027	.02
.65	.02	.017	.015
.75	.016	.015	.015
.825	.013	.014	.015
.875	.010	.01	.01
.925	.01	.008	.007
.975	.01	.007	.005

TAPER RATIO=1.0

.05	.245	.215	.185
.15	.210	.185	.16
.25	.125	.102	.08
.35	.08	.065	.05
.45	.05	.04	.03
.55	.03	.025	.02
.65	.02	.017	.015
.75	.015	.015	.015
.825	.010	.012	.015
.875	.008	.009	.01
.925	.008	.008	.007
.975	.008	.007	.005

Table II
Values of span loading factor G/δ_1 from reference 3 for wings with inboard flaps; $\eta_f = .556\ b/2$

TAPER RATIO=.667

STATION	ASPECT RATIO=6	ASPECT RATIO=8	ASPECT RATIO =10
.05	.40	.343	.285
.15	.395	.340	.285
.25	.385	.332	.280
.35	.355	.302	.25
.45	.30	.255	.21
.55	.235	.192	.15
.65	.14	.113	.085
.75	.085	.065	.045
.825	.055	.042	.03
.875	.045	.035	.025
.925	.040	.030	.02
.975	.025	.022	.02
1.0	0		

TAPER RATIO=1.0

STATION	ASPECT RATIO=6	ASPECT RATIO=8	ASPECT RATIO =10
.05	.375	.312	.25
.15	.37	.315	.26
.25	.36	.307	.255
.35	.33	.28	.23
.45	.29	.245	.20
.55	.235	.192	.15
.65	.13	.107	.085
.75	.06	.052	.045
.825	.03	.03	.03
.875	.025	.025	.025
.925	.025	.022	.02
.975	.025	.022	.02

Table III
Values of span loading factor G/δ_1
from reference 3 for wings with
full span flaps $\eta_f = 1.0\ b/2$

TAPER RATIO=0.667

	ASPECT RATIO=6	ASPECT RATIO=8	ASPECT RATIO=10
.05	.445	.379	.313
.15	.442	.375	.307
.25	.433	.365	.296
.35	.419	.353	.286
.45	.40	.337	.274
.55	.378	.319	.259
.65	.347	.293	.238
.75	.31	.263	.216
.825	.265	.229	.192
.875	.225	.198	.170
.925	.186	.161	.135
.975	.107	.09	.073

TAPER RATIO=1.0

.05	.41	.345	.28
.15	.41	.345	.28
.25	.408	.343	.278
.35	.403	.338	.273
.45	.395	.33	.265
.55	.388	.322	.255
.65	.360	.303	.245
.75	.315	.273	.23
.825	.275	.24	.205
.875	.240	.21	.18
.925	.20	.173	.145
.975	.12	.10	.08

Table IV
Values of span loading factor G/δ_1 from reference 3 for wings with outboard flaps, $\eta_f = 0.805\ b/2$

TAPER RATIO=0.667

	ASPECT RATIO=6	ASPECT RATIO=8	ASPECT RATIO =10
.05	.185	.144	.103
.15	.217	.175	.132
.25	.293	.25	.206
.35	.334	.285	.236
.45	.34	.292	.244
.55	.343	.292	.239
.65	.327	.276	.223
.75	.294	.248	.201
.825	.252	.215	.177
.875	.215	.188	.16
.925	.176	.153	.128
.975	.097	.083	.068

TAPER RATIO=1.0

.05	.165	.13	.095
.15	.20	.16	.12
.25	.283	.24	.20
.35	.323	.273	.223
.45	.345	.29	.235
.55	.358	.296	.235
.65	.340	.285	.23
.75	.30	.258	.215
.825	.265	.228	.19
.875	.232	.201	.17
.925	.192	.165	.138
.975	.112	.094	.075

Table V
Values of span loading factor, G/δ_1 from reference 3 for wings with outboard flaps, η_f=0.444 b/2

TAPER RATIO=0.667

	ASPECT RATIO=6	ASPECT RATIO=8	ASPECT RATIO=10
.05	.047	.039	.03
.15	.046	.035	.024
.25	.051	.035	.02
.35	.071	.053	.036
.45	.099	.084	.068
.55	.152	.134	.116
.65	.204	.177	.151
.75	.220	.193	.166
.825	.203	.184	.165
.875	.178	.163	.148
.925	.149	.137	.125
.975	.09	.076	.063

TAPER RATIO=1.0

.05	.035	.031	.028
.15	.038	.03	.023
.25	.05	.036	.023
.35	.073	.055	.038
.45	.103	.084	.065
.55	.16	.136	.113
.65	.218	.188	.158
.75	.225	.203	.18
.825	.213	.196	.178
.875	.193	.176	.158
.925	.163	.144	.125
.975	.103	.087	.07

TABLE VI

CHARACTERISTICS OF WINGS ANALYZED

WING	W/S (lb/Ft^2)	ASPECT RATIO	TAPER RATIO	FLAP SPAN η_f	WING AREA (Ft^2)	WING SPAN (Ft)	WEIGHT (lbs)
N1	25	6.04	1.0	None	326.6	44.417	8160
N2	25	8.0	1.0	None	326.6	51.116	8160
N3	25	10	1.0	None	326.6	57.149	8160
N4	25	6	.667	None	240	44'	6000
N5	25	8	.667	None	240	44'	6000
N6	25	10	.667	None	240	44'	6000
N7	25	6	.5	None	326.6	44.4'	8160
N8	25	8	.5	None	326.6	51,116'	8160
N9	25	10	.5	None	326.6	57.149'	8160
N10	25	8	1.0	None	450	60	11250
N11	25	7.5	.667	None	450	58.095	11250
N12	25	8	.667	None	450	60	11250
N13	25	8	1.0	* Inb=.556	326.6	51.116	8160
N14	15	8	1.0	Inb=.556	326.6	51.116	8160
N15	25	8	.667	Inb=.556	326.6	51.116	8160
N16	15	8	.667	Inb=.556	326.6	51.116	8160
N17	25	8	.5	Inb=.556	326.6	51.116	8160

* inboard of station η_f

TABLE VII

CHARACTERISTICS OF WINGS ANALYZED

WING	W/S (lb/ft^2)	ASPECT RATIO	TAPER RATIO	FLAP SPAN η_f	WING AREA (ft^2)	WING SPAN (ft)	WEIGHT (lbs)
N18	15	8	.5	Inb=.556	326.6	51.116	5000
N19	25	8	.667	Inb=.556	450	60	11250
N20	25	10	.667	None	450	67.082	11250
N21	25	8	.667	None	326.6	51.116	8160
N22	25	8	1.0	Inb=.195	326.6	51.116	8160
N23	25	8	.667	Inb=.195	326.6	51.116	8160
N24	25	8	1.0	Inb=.195	450	60	11250
N25	25	8	.667	Inb=.195	450	60	11250
N26	25	6	.667	None	326.6	44.417	8160
N27	25	10	.667	None	326.6	57.149	8160
N28	25	6	.667	None	450	51.962	11250
N29	25	8	1.0	* O.B.0.444	326.6	51.116	8160
N30	25	8	1.0	O.B.0.805	326.6	51.116	8160
N31	25	8	0.667	O.B.0.444	326.6	51.116	8160
N32	25	8	0.667	O.B.0.805	326.6	51.116	8160
N33	25	8	1.0	O.B.0.444	450	60	11250
N34	25	8	1.0	O.B.0.805	450	60	11250

* outboard of station η_f

TABLE VIII

CHARACTERISTICS OF WINGS ANALYZED

WING	W/S (lb/ft^2)	ASPECT RATIO	TAPER RATIO	FLAP SPAN η_f	WING AREA (ft^2)	WING SPAN (ft)	WEIGHT (lbs)
N35	25	8	0.667	O.B.0.444	450	60	11250
N36	25	8	0.667	O.B.0.805	450	60	11250
N37	30	8	.667	None	327	51.116	9810
N38	35	8	.667	None	327	51.116	11445
N39	40	8	.667	None	327	51.116	13080
N40	30	8	.667	Inb=.556	327	51.116	9810
N41	35	8	.667	Inb=.556	327	51.116	11445
N42	40	8	.667	Inb=.556	327	51.116	13080
N43	30	6	.667	None	327	44.3'	9810
N44	35	6	.667	None	327	44.3'	11445
N45	40	6	.667	None	327	44.3'	13080
N46	30	6	.667	Inb=.556	327	44.3'	9810
N47	35	6	.667	Inb=.556	327	44.3'	11445
N48	40	6	.667	Inb=.556	327	44.3'	13080

User Instructions

APPENDIX A
Hewelett Packard 97-7,
SPAN LOADING ANALYSIS

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
I	Enter Data	Reg		
	G/δ_1	0		
	Span Station , % $^b/_2$,	1		
	Δy, % $^b/_2$, decimal	2		
	P ⇌ S			
	Wing Span, b	0		
	Wing Area, S	1		
	Taper Ratio, λ	2		
	Gross Weight W	3		
	Air Density, ρ	4		
	Airplane C_L	5		
		6		
		7		
		8		
	Airplane Speed, ft./sec, input for			
	Constant C_L	9		
	P ⇌ S			
II	Press A for first run			
III	Enter data for 2nd run, yn			
	G/δ_1	0		
	yn	1		
	Δy	2		
	Press B			
IV	Repeat Step III. On last step			
	store 1 in Register I, Press B			
	Program prints out C_L as last item.			
V	STO first value of Δy in	1		
	$\Delta y/b/2$	2		
	P ⇌ S			
	$c_1 \times c_y$			
	P ⇌ S	8		
VI	Press C. Using same entries			
	press D.			
VII	Repeat VI for as many steps as nec-			
	essary. Last step should be y=1.0			
	& $c_1 \times c_y = 0$, last print-out will			
	be shed vorticity at tip of wing			

User Instructions

APPENDIX A (continued)
Hewelett Packard 97-7,
SPAN LOADING ANALYSIS

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
	DATA STORAGE			
REG				
1	G/δ_1 (From Tables I-V)			
2	$^y/\ b/2$	%		
3	Δy	FT.		
4				
5				
6				
7				
8				
9				
10				
A				
B				
C				
D				
E				
I				
10	Wing Span, Ft.	FT.		
11	Wing Area, $Ft.^2$	$FT.^2$		
12	Taper Ratio, $^{Ct}/Cr$, λ			
13	Weight, # lb	lb		
14	Air Density-Slugs/Cu. Ft., ρ			
15	Wing C_L			
16	Cr	FT.		
17	Ct	FT.		
18	$c_{l_y} \times c_y$			
19	V	FT./SEC.		
	using W/S, ρ & C_L			

Hewlett Packard
H. P. 97

APPENDIX A (continued)

Date ________
Sheet ________

SPAN LOADING ANALYSIS

I. Wing, Airplane and Operating Data

Identification ____________________

		Register
Wing Span ________ ft. ________ m		____
Wing Area ________ sq.ft. ________ sq.m		____
Taper Ratio ________		____
Operating Weight ________ # ________ kg		____
Air Density ________ slugs/cu.ft. ________ kg/m^3		____
Wing C_L ________ (for C_L =constant)		____
Swath Speed ________ mph ________ Kphr		____
Root Chord ________ ft. ________ m		____
Tip Chord ________ ft. ________ m		____
Aspect Ratio ________		____

Flap:
Type ________
Chord ________ %, Span ________ %
$dC_L/d\alpha$ ________, $d\alpha/d\delta_f$ ________, Up to δ_f = ________

INPUT DATA, RUNS [A] & [B]

G/δ_1 Reg.0	y/b/2 Reg.1	Δ y Reg.2	Start Program	C_y
			[A]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	
			[B]	

PRINT REGISTERS

SPAN LOADING ANALYSIS, PART II	APPENDIX A (continued)	HEWLETT PACKARD H.P. 97

WING IDENTIFICATION________________________ SHEET____________

INPUT DATA, RUNS [C] & [D]

$y/b/2$ REG. 1	Δy REG. 2		$c_{l_y} \times c_y$ REG. 8		PRESS	Γ	$\Delta\Gamma$
		P⇄S		P⇄S	C		
	SAME ENTRIES				D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		
		P⇄S		P⇄S	D		

PROGRAM LISTING H.P. 97-7

Span Loading Analysis

Step	Key Entry
001	LBLA
002	DSP3
003	SPC
004	SPC
005	SPC
006	P⇌S
007	RCL0
008	PRTX
009	RCL1
010	PRTX
011	RCL2
012	PRTX
013	RCL3
014	PRTX
015	RCL4
016	PRTX
017	RCL5
018	PRTX
019	RCL2
020	1
021	+
022	RCL0
023	X
024	1/X
025	RCL1
026	X
027	2
028	X
029	STO6
030	PRTX
031	RCL2
032	X
033	PRTX
034	STO7
035	RCL3
036	RCL1
037	÷
038	RCL4
039	÷
040	RCL5
041	÷
042	2
043	X
044	√x
045	PRTX
046	STO9
047	P⇌S
048	SPC
049	SPC
050	RCL1
051	PRTX
052	SPC
053	0
054	STOE
055	0
056	STOI
057	LBLB
058	RCL0
059	PRTX
060	P⇌S
061	RCL0
062	X
063	2
064	X
065	PRTX
066	STO8
067	RCL2
068	CHS
069	1
070	+
071	P⇌S
072	RCL1
073	X
074	CHS
075	1
076	+
077	P⇌S
078	RCL6
079	X
080	PRTX
081	STOA
082	1/X
083	RCL8
084	X
085	P⇌S
086	STOB
087	PRTX
088	RCL1
089	P⇌S
090	RCL0
091	X
092	2
093	÷
094	P⇌S
095	PRTX
096	STOC
097	RCL2
098	P⇌S
099	RCL0
100	X
101	2
102	÷
103	RCLA
104	X
105	PRTX
106	STOD
107	RCL8
108	RCL0

APPENDIX A (Continued)

PROGRAM LISTING
Span Loading Analysis

H.P. 97-7

Step	Key Entry
109	X
110	2
111	÷
112	P⇌S
113	RCL2
114	X
115	RCLE
116	+
117	STOE
118	PRTX
119	RCLI
120	X=0?
121	GTOE
122	RCLE
123	P⇌S
124	RCL1
125	÷
126	2
127	X
128	SPC
129	PRTX
130	P⇌S
131	STO3
132	LBLE
133	SPC
134	RTN
135	LBLC
136	RCL3
137	5
138	7
139	.
140	3
141	÷
142	STO4
143	PRTX
144	1
145	5
146	STOI
147	RCLi
148	RCL3
149	÷
150	STO5
151	PRTX
152	LBLD
153	P⇌S
154	RCL8
155	RCL9
156	X
157	2
158	÷
159	P⇌S
160	RCL5
161	X
162	STO6
163	PRTX
164	STO8
165	RCL7
166	RCL8
167	-
168	PRTX
169	RCL9
170	+
171	STO9
172	RCL8
173	STO7
174	SPC
175	SPC
176	RCLI
177	X<0?
178	GTO1
179	R/S
180	LBL1
181	RTN
182	R/S

H.P. 97 COMPUTER LISTING CODE

Sample run for wing N-27 (See Table VII).

PART I

INPUT DATA

```
         CLRG
.313     ST00
.050     ST01
.100     ST02
         P⇄S
57.149   ST00
326.600  ST01
.667     ST02
8160.000 ST03
.002378  ST04
.807     ST05
         P⇄S
         GSBA
```

57.149	***	WING SPAN FT
326.600	***	WING AREA, SQ FT
0.667	***	λ, TAPER RATIO
8160.000	***	GROSS WT., #
0.002	***	ρ = AIR DENSITY
0.807	**	WING C_L
6.856	***	C_r, ROOT CHORD
4.573	***	C_t, TIP CHORD
161.365	***	V, FT/SEC
0.050	***	SPAN STATION y/b/2
0.313	***	G/S, (REF 1071)
35.775	***	$C_l \times C_y$
6.742	***	C_y
5.306	***	C_{l_y}
1.429	***	y, FT FROM ℄
19.266	***	Δ AREA, SQ. FT
102.226	***	(C_{l_y} x Δ AREA)
.307	ST00	G/S, AT
.150	ST01	y/(b/2)
	GSBB	
0.307	***	G/S,
35.089	***	$C_l \times C_y$
6.514	***	C_y
5.387	***	C_{l_y}
4.286	***	y, FT
18.613	***	Δ AREA
202.493	***	(C_{l_y} x Δ AREA)
.296	ST00	
.250	ST01	
	GSBB	
0.296	***	
33.832	***	
6.286	***	
5.382	***	
7.144	***	
17.961		
299.166		

COMPUTATION FOR NEXT OUTBOARD SPAN STATION

```
.286    ST00
.350    ST01
        GSBB
0.286   ***
32.689  ***
6.057   ***
5.397   ***
10.001  ***
17.309  ***
392.574 ***

.274    ST00
.450    ST01
        GSBB
0.274   ***
31.318  ***
5.829   ***
5.373   ***
12.859  ***
16.656  ***
482.063 ***

.259    ST00
.550    ST01
        GSBB
0.259   ***
29.603  ***
5.601   ***
5.286   ***
15.716  ***
16.004  ***
566.652 ***

.238    ST00
.650    ST01
        GSBB
0.238   ***
27.203  ***
5.372   ***
5.063   ***
18.573  ***
15.351  ***
644.383 ***

.216    ST00
.750    ST01
        GSBB
0.216   ***
24.680  ***
5.144   ***
4.753   ***
21.431
14.699
714.929
```

```
.192    ST00
.825    ST01
.050    ST02
        GSBB
0.192   ***
21.945  ***
4.973   ***
4.413   ***
23.574  ***
7.105   ***
746.283 ***

.170    ST00
.875    ST01
        GSBB
0.170   ***
19.431  ***
4.859   ***
3.999   ***
25.003  ***
6.942   ***
774.044 ***

.135    ST00
.925    ST01
        GSBB
0.135   ***
15.430  ***
4.745   ***
3.252   ***
26.431  ***
6.779   ***
796.089 ***

.073    ST00
.975    ST01
1.000   ST01
        GSBB
0.073   ***
8.344   ***
4.630   ***
1.802   ***
27.860  ***
6.616   ***
808.010 ***
4.948   ***
```

4.948 — WING C_L AT α = 1 RADIAN

H.P. 97 COMPUTER LISTING CODE

PART II

PREG

0.073	0
0.975	1
0.050	2
4.948	3
0.000	4
0.000	5
0.000	6
0.000	7
0.000	8
0.000	9
4.630	A
1.802	B
27.860	C
6.616	D
808.010	E
1.000	I

← INPUT DATA

P⇄S
PREG

57.149	0
726.600	1
0.667	2
6160.000	3
0.002	4
0.807	5
6.856	6
4.572	7
8.344	8
161.365	9
4.630	A
1.802	B
27.860	C
6.616	D
808.010	E
1.000	I

```
          P⇄S
   .050   STO1    y of midpoint of Δy
   .100   STO2    Δy, % b/2
          P⇄S
 35.775   STO8    Cℓy × Cy
          P⇄S
          GSBC
  0.086   ***
  0.163   ***
470.762   ***
-470.762  ***

          GSBD
470.762
  0.000
```

```
   .150   STO1
          P⇄S
 35.089   STO8
          P⇄S
          GSBD
461.735   ***     Γ AT y
  9.027   ***     ΔΓ

   .250   STO1
          P⇄S
 33.832   STO8
          P⇄S
          GSBD
445.194   ***
 16.541   ***

   .350   STO1
          P⇄S
 32.689   STO8
          P⇄S
          GSBD
430.154   ***
 15.041   ***

   .450   STO1
          P⇄S
 31.318   STO8
          P⇄S
          GSBD
412.113   ***
 18.041   ***

   .550   STO1
          P⇄S
 29.603   STO8
          P⇄S
          GSBD
389.545   ***
 22.568   ***

   .650   STO1
          P⇄S
 27.283   STO8
          P⇄S
          GSBD
357.964
 31.582
```

```
   .750   STO1
          P⇄S
 24.668   STO8
          P⇄S
          GSBD
324.869   ***
 33.095   ***

   .825   STO1
   .050   STO2
          P⇄S
 21.945   STO8
          P⇄S
          GSBD
288.774   ***
 36.095   ***

   .875   STO1
          P⇄S
 19.431   STO8
          P⇄S
          GSBD
255.692   ***
 33.082   ***

   .925   STO1
          P⇄S
 15.430   STO8
          P⇄S
          GSBD
203.043   ***
 52.649   ***

   .975   STO1
          P⇄S
  8.344   STO8
          P⇄S
          GSBD
109.798   ***
 93.244   ***

  1.000   STO1
          P⇄S
  0.000   STO8
          P⇄S
          GSBD
  0.000   ***
109.798   ***
```

APPENDIX B

BASIC program for SPAN LOADING ANALYSIS

file name="SPNLA"

LIST

```
1       POKE 41993, 32
10      PRINT "1071 SPAN LOADING ANALYSIS"
11      DIM DELY (13), GDEL (13)
12      M=1
14      INPUT "FLAP SPAN =";FSP
16      INPUT "SPEED COMPUTATION=";X
17      VFPS=139
18      WT=6000
20      AREA=327
22      RHO=0.002378
24      CL=0.8
26      IF X=1 then 30
28      GOTO 36
30      VFPS= SQR (WT/ (AREA*RHO/2*CL))
32      PRINT "SPEED=";VFPS
34      GOTO 40
36      CL=WT/ (RHO/2*VFPS'2*AREA)
38      PRINT "LIFT COEFFICIENT=";CL
40      INPUT "SPAN=";SPAN
42      INPUT"TAPER RATIO=";TR
44      INPUT"ASPECT RATIO":ASPR
45      CR=(2*AREA)/(Span*(1+TR))
46      PRINT"CR=";CR
47      FOR I= 1 TO 13
49      READ DELY (I), GDEL (I)
50      NEXT I
51      DELY=DELY (M)
52      GDEL=GDEL (M)
53      K=1-DELY
54      IF K=0 THEN 80
62      CT=TR*CR
64      CY=CR*(1-(DELY*(1-TR)))
65      YCL=2*SPAN*GDEL/CY
66      IF DELY >0.75 THEN 69
67      YINC=0.1
68      GOTO 75
69      YINC=0.05
75      SMCL=SMCL+YCL*CY*YINC*SPAN
76      M=M+1
77      GOTO 51
80      RCL=SMCL/AREA
82      MULT=CL/RCL
84      SLC=RCL/57.3
90      M=1
```

Page two

```
 91      DELY=DELY (M)
 92      GDEL=GDEL (M)
102      K=1-DELY
104      IF K=0 THEN 160
106      CY=CR* (1-DELY*(1-TR))
108      YCL=2*SPAN*GDEL/CY
110      IF DELY > 0.75 THEN  115
112      YINC=0.1
113      GOTO 120
115      YINC=0.05
120      GAM=YCL*CY*VFPS/2
125      GAM=GAM*MULT
126      SGAM=SGAM+GAM*YINC*SPAN/2
130      PRINT"SPAN STATION=";DELY
132      PRINT"CY=";CY
134      PRINT"CLY="; YCL
140      PRINT"GAMMA=";GAM
142      PRINT" "
143      M=M+1
144      GOTO 91
160      PRINT" "
162      PRINT"CL/RADIAN=";RCL
164      PRINT"LIFT CURVE SLOPE=";SLC
165      PRINT"CT=";CT
166      AVGM=SCAM/(Span/2)
170      DATA 0.05,0.379,0.15,0.375,0.25,0.365
171      DATA 0.35,0.353,0.45,0.337,0.55,0.319
172      DATA 0.65,0.292,0.75,0.263,0.825,0.299
173      DATA 0.875,0.198,0.925,0.161,0.975,0.09, 1, 0
176      PRINT"AVG GAMMA=";AVGM
200      STOP
```

BASIC SPAN LOADING ANALYSIS

OUTPUT LISTING SPNLA

```
18 WT=13080

RUN
1071 SPAN LOADING AN
ALYSIS
FLAP SPAN=? 1
SPEED COMPUTATION=?
1
SPEED= 205.066196
SPAN=? 51.116
TAPER RATIO=? .667
ASPECT RATIO=? 8
CR= 7.67512199
SPAN STATION= .05
CY= 7.54733121
CLY= 5.13372568
GAMMA= 658.096692

SPAN STATION= .15
CY= 7.291745[illegible]5
CLY= 5.25758588
GAMMA= 651.15108

SPAN STATION= .25
CY= 7.03616809
CLY= 5.30326729
GAMMA= 633.787051

SPAN STATION= .35
CY= 6.7805865[illegible]
CLY= 5.32223[illegible]
GAMMA= [illegible]95.216

SPAN STATION= .45
CY= 6.5250[illegible]
CLY= 5.2800[illegible]
GAMMA= [illegible]77

SPAN STATION= .55
CY= 6.2694234
CLY= 5.20175555
GAMMA= 553.912518

SPAN STATION= .65
CY= 6.01384184
CLY= 4.96383923
GAMMA= 507.029641

SPAN STATION= .75
CY= [illegible].75826027
CLY= [illegible].66929[illegible]02
GAMMA= 456.6[illegible]958

SPAN STATION= .825
CY= 5.5665741
CLY= 4.20566179
GAMMA= 397.63626

SPAN STATION= .875
CY= 5.43878332
CLY= 3.72177651
GAMMA= 343.80777

SPAN STATION= .925
CY= 5.3109925[illegible]
CLY= 3.09911[illegible]6
GAMMA= 279.56[illegible]

SPAN STATION= .975
CY= 5.18320[illegible]
CLY= 1.77513[illegible]5
GAMMA= 156.27[illegible]

CL/RADIAN=
 4.8293694
LIFT CURVE SLOPE=
 .0842821886
CT= 5.11930637
AVG GAMMA=
 524.74095
 BREAK IN  200

PRINT .002378*51.116
 5524.74*205.1
 137735.604

PRINT .002378*524.74
 51.116*205.1
 13082.1325
```

BASIC program for SPAN LOADING ANALYSIS

file name="SPNLB"

This version of the span loading analysis program is the same as SPNLA except for the following statements:

```
17    INPUT "VFPS="; VFPS
18    INPUT "WEIGHT="; WT.
20    INPUT "WING AREA ="; AREA
22    INPUT "DENSITY="; RHO
24    INPUT "LIFT COEFF="; CL
```

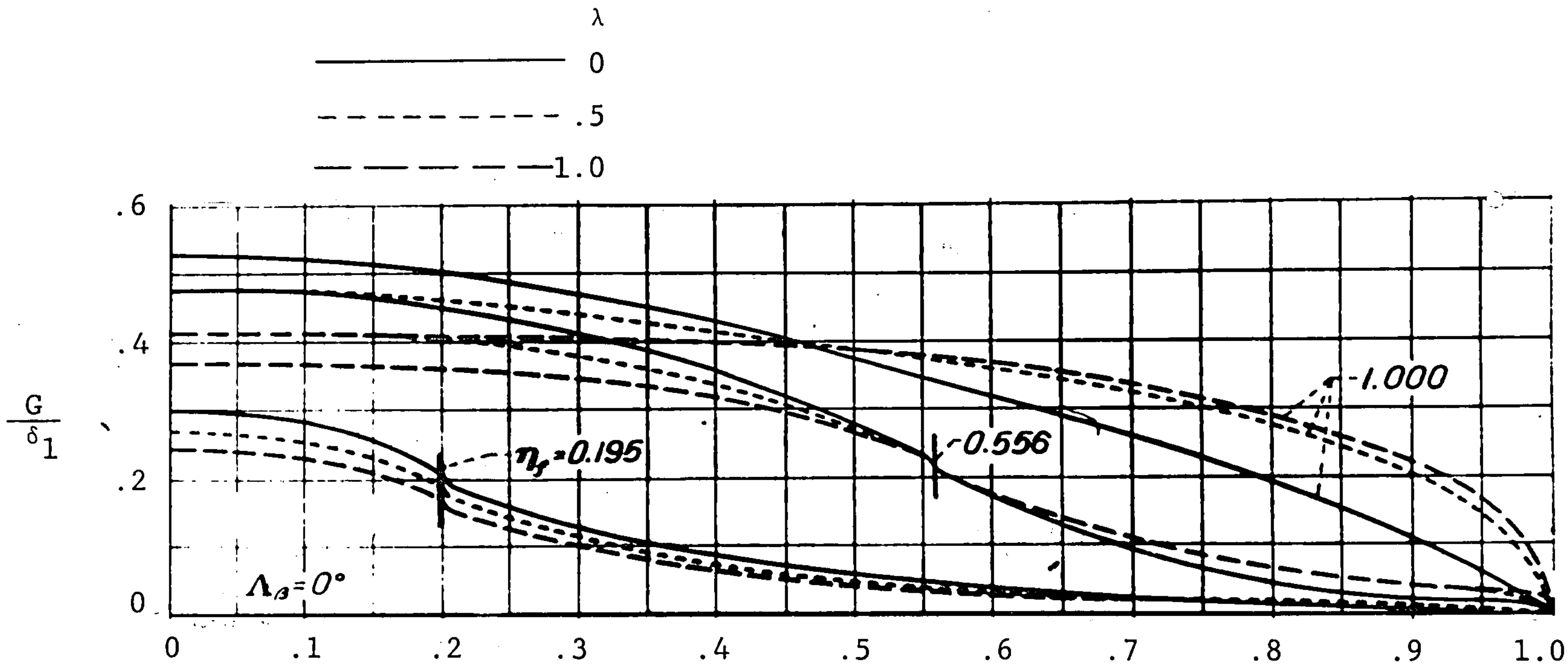
All succeeding statements are the same as SPNLA.

APPENDIX B (Continued)

COMPUTER OUTPUT LISTING for BASIC Span Loading Analysis

file name="SPNLB"

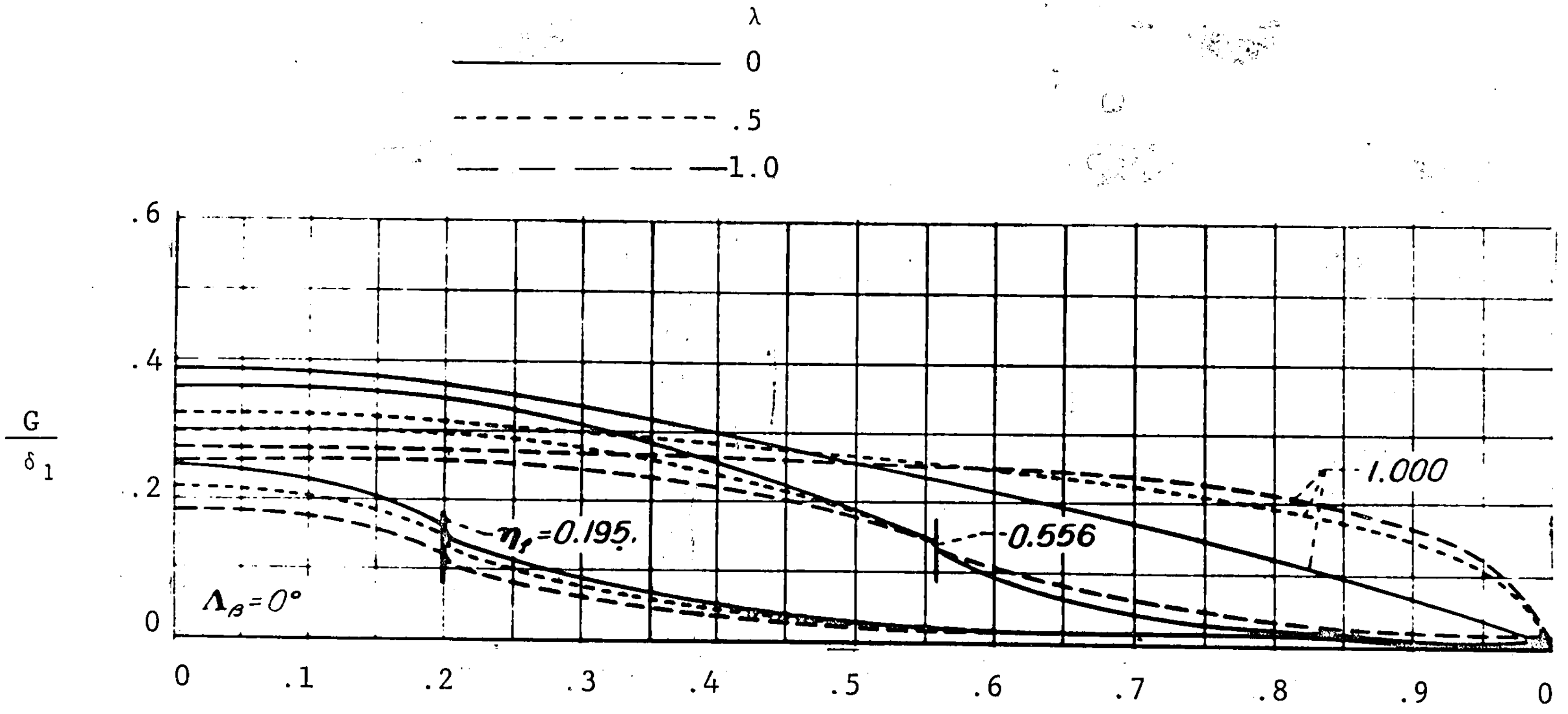
```
RUN
1071 SPAN LOADING AN
ALYSIS
FLAP SPAN=? 1
SPEED COMPUTATION=?
1
VFPS=? 139
WEIGHT=? 6000
WING AREA=? 227
DENSITY=? .002378
LIFT COEFF=? .8
SPEED= 138.888353
SPAN=? 51.116
TAPER RATIO=? .667
ASPECT RATIO=? 8
CR= 7.67512199
SPAN STATION= .05
CY= 7.54733121
CLY= 5.13372568
GAMMA= 445.719321

SPAN STATION= .15
CY= 7.29174965
CLY= 5.25758588
GAMMA= 441.01516

SPAN STATION= .25
CY= 7.03616809
CLY= 5.30326729
GAMMA= 429.254755

SPAN STATION= .35
CY= 6.78058653
CLY= 5.32223811
GAMMA= 415.14227

SPAN STATION= .45
CY= 6.52500496
CLY= 5.28002419
GAMMA= 396.325624

SPAN STATION= .55
CY= 6.2694234
CLY= 5.20175555
GAMMA= 375.156896

SPAN STATION= .65
CY= 6.01384184
CLY= 4.96383923
GAMMA= 343.403804

SPAN STATION= .75
CY= 5.75826027
CLY= 4.66929502
GAMMA= 309.298632

SPAN STATION= .85
CY= 5.5665741
CLY= 4.20566179
GAMMA= 269.31325

SPAN STATION= .875
CY= 5.43878332
CLY= 3.72177651
GAMMA= 232.856004

SPAN STATION= .925
CY= 5.31099254
CLY= 3.09911036
GAMMA= 189.3425

SPAN STATION= .975
CY= 5.18320176
CLY= 1.77513445
GAMMA= 105.843638

CL/RADIAN=
 4.8293694
LIFT CURVE SLOPE=
 .0842821886
CT= 5.11930637
AVG GAMMA=
 355.399417
BREAK IN  200
```



Spanwise load distribution factor, $\frac{G}{\delta_1}$, per radian.

Aspect ratio = 6.0

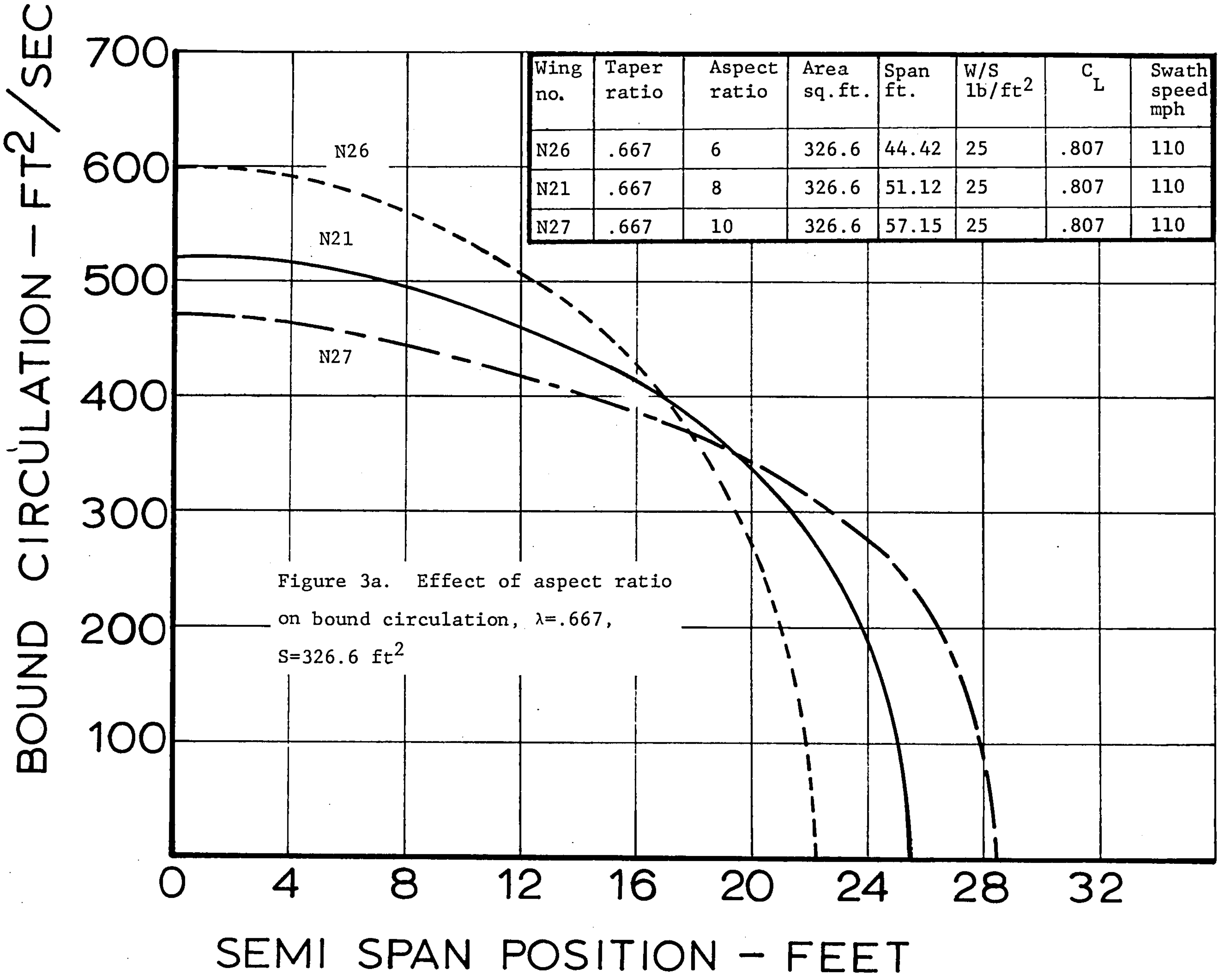
FIGURE 1.



Spanwise load distribution factor, $\frac{G}{\delta_1}$, per radian.

Aspect ratio = 10.0

FIGURE 2



Wing no.	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N26	.667	6	326.6	44.42	25	.807	110
N21	.667	8	326.6	51.12	25	.807	110
N27	.667	10	326.6	57.15	25	.807	110

Figure 3a. Effect of aspect ratio on bound circulation, λ=.667, S=326.6 ft^2

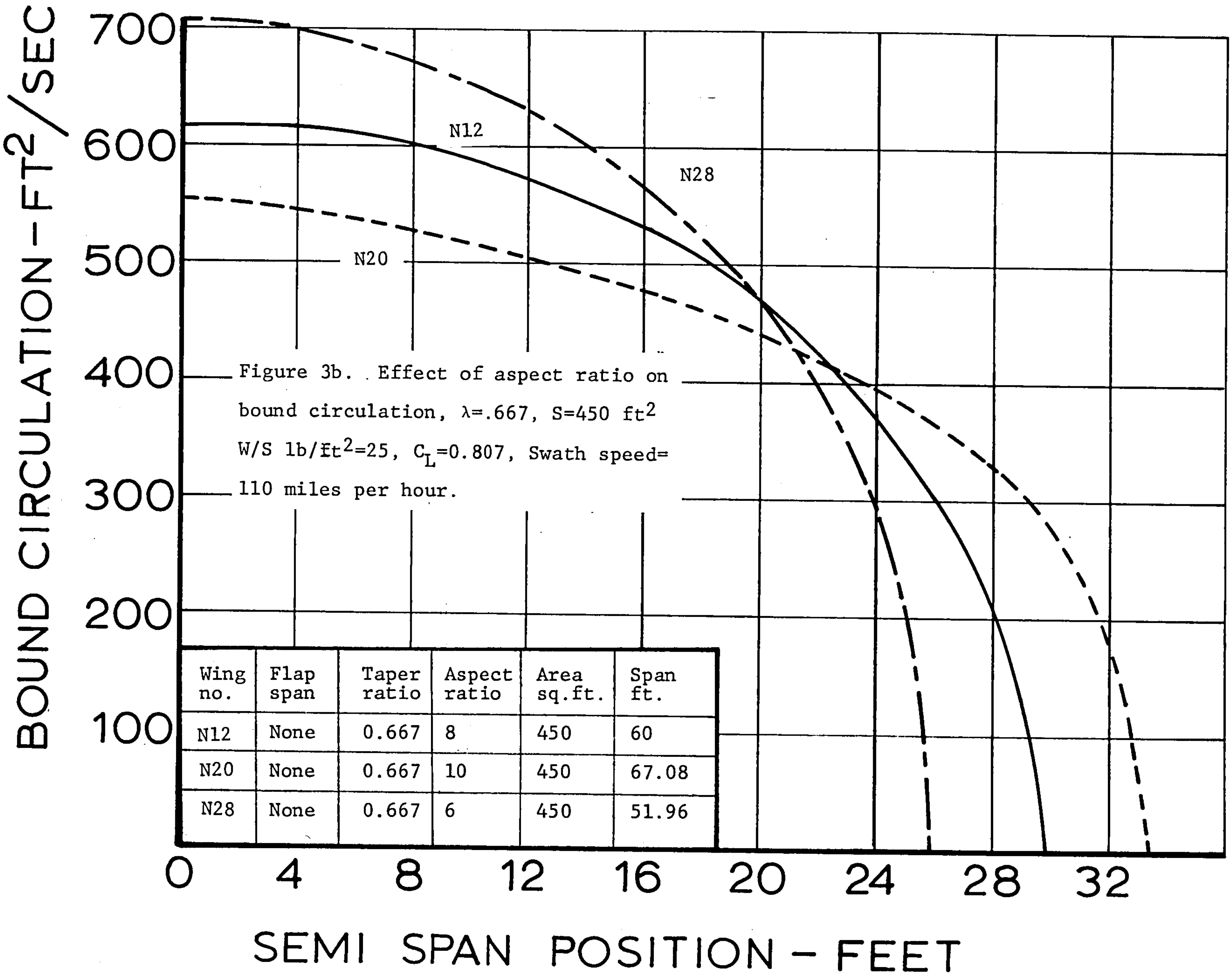
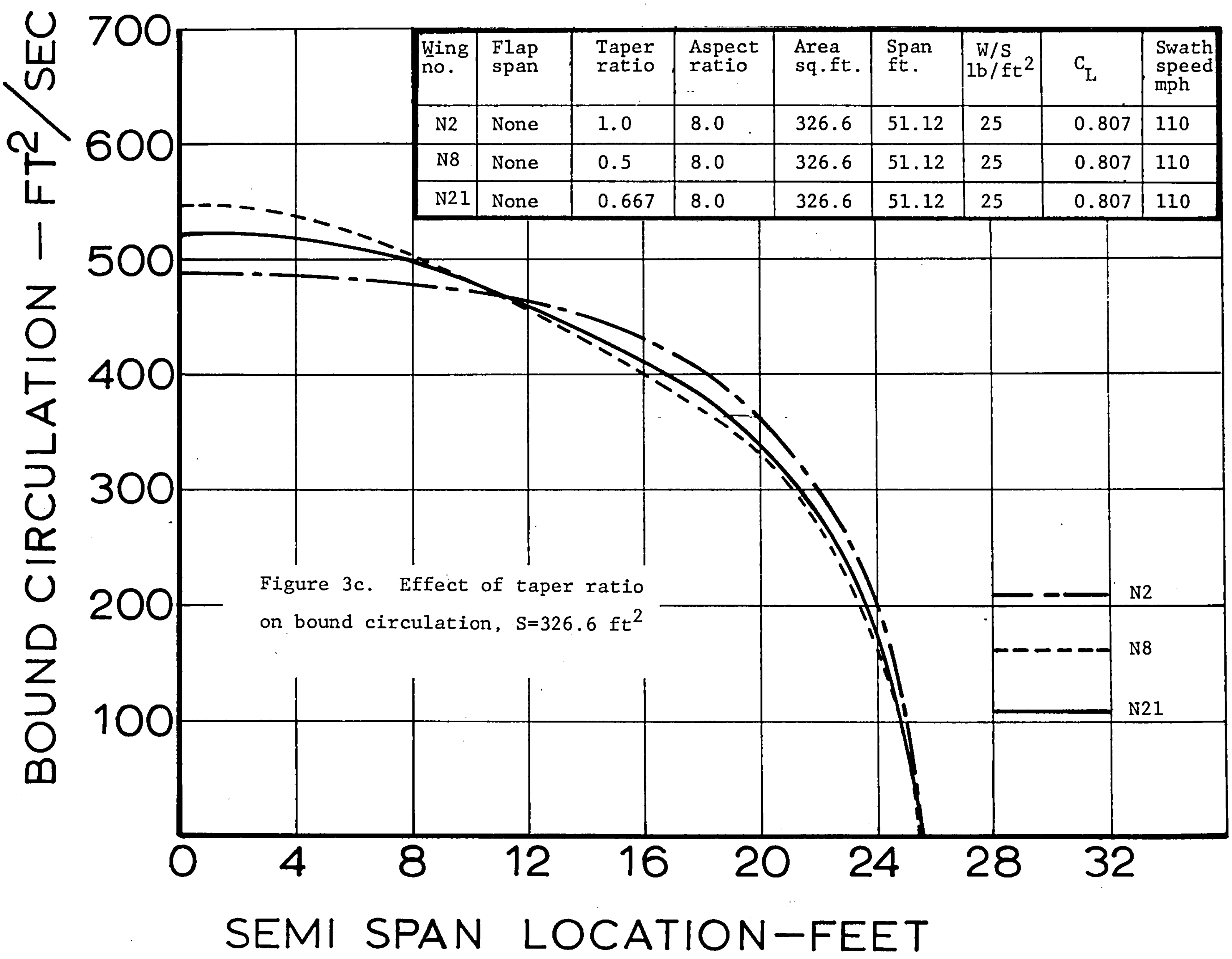


Figure 3b. Effect of aspect ratio on bound circulation, λ=.667, S=450 ft^2 W/S lb/ft^2=25, C_L=0.807, Swath speed= 110 miles per hour.

Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.
N12	None	0.667	8	450	60
N20	None	0.667	10	450	67.08
N28	None	0.667	6	450	51.96



Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N2	None	1.0	8.0	326.6	51.12	25	0.807	110
N8	None	0.5	8.0	326.6	51.12	25	0.807	110
N21	None	0.667	8.0	326.6	51.12	25	0.807	110

Figure 3c. Effect of taper ratio on bound circulation, $S=326.6\ ft^2$

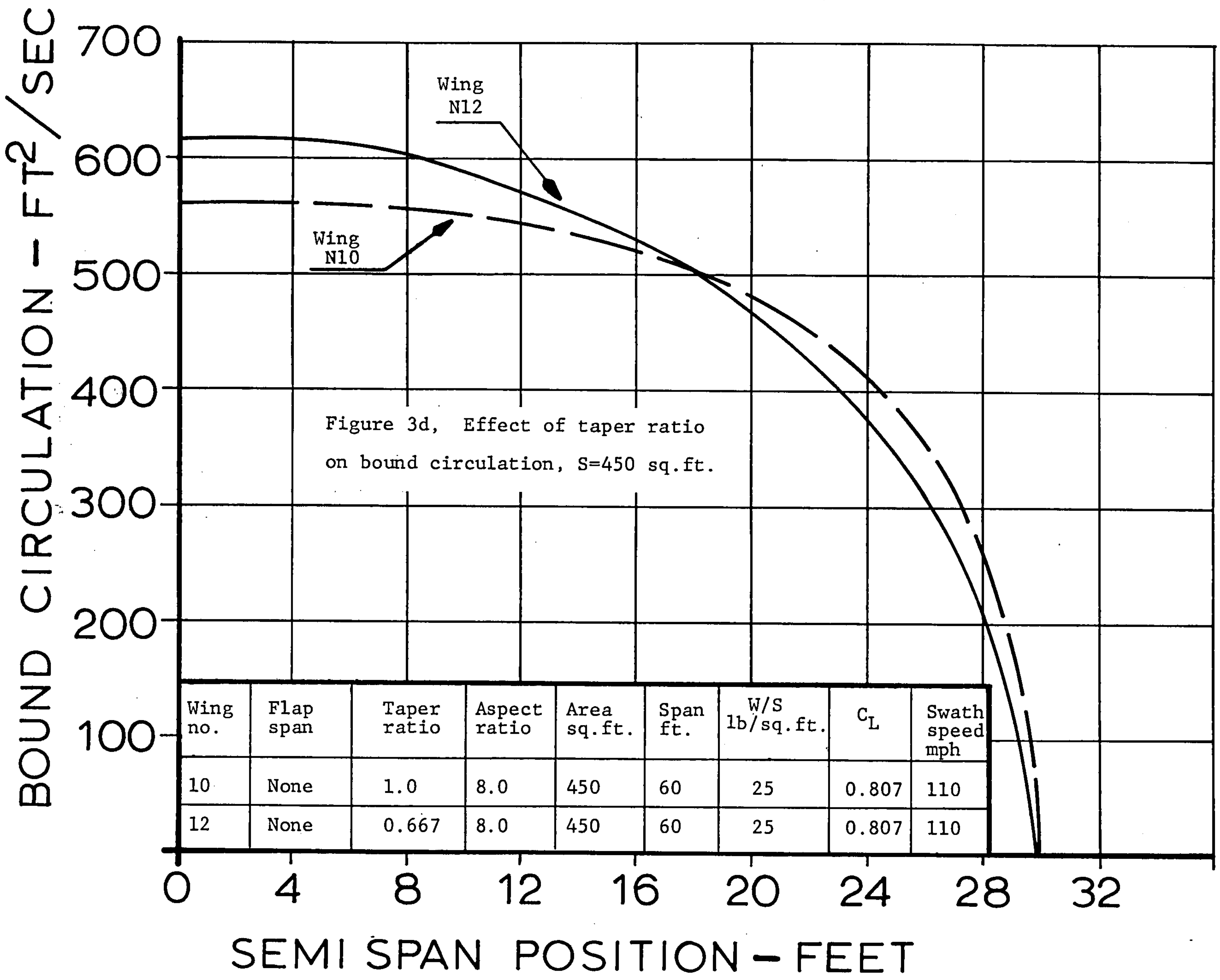
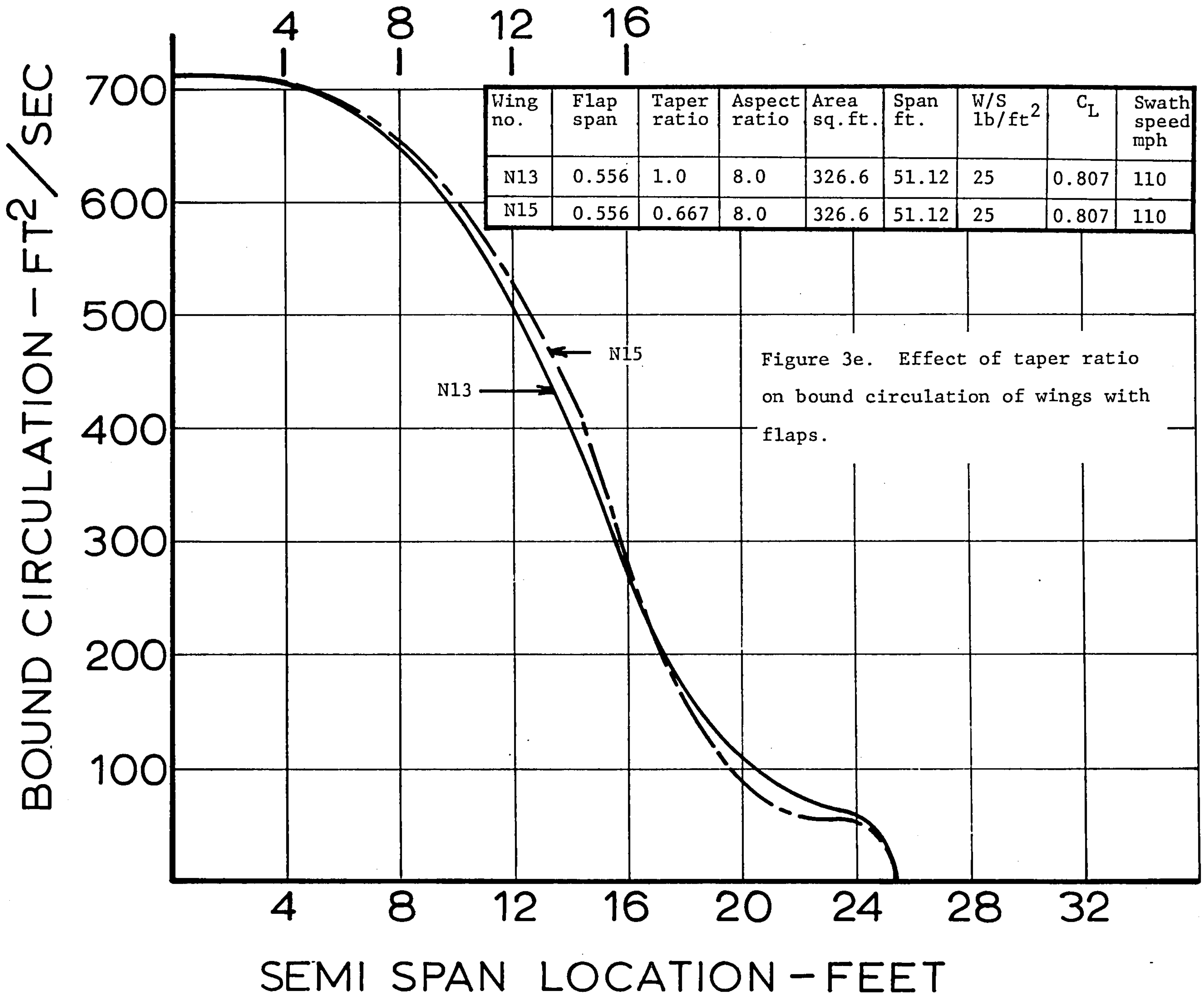


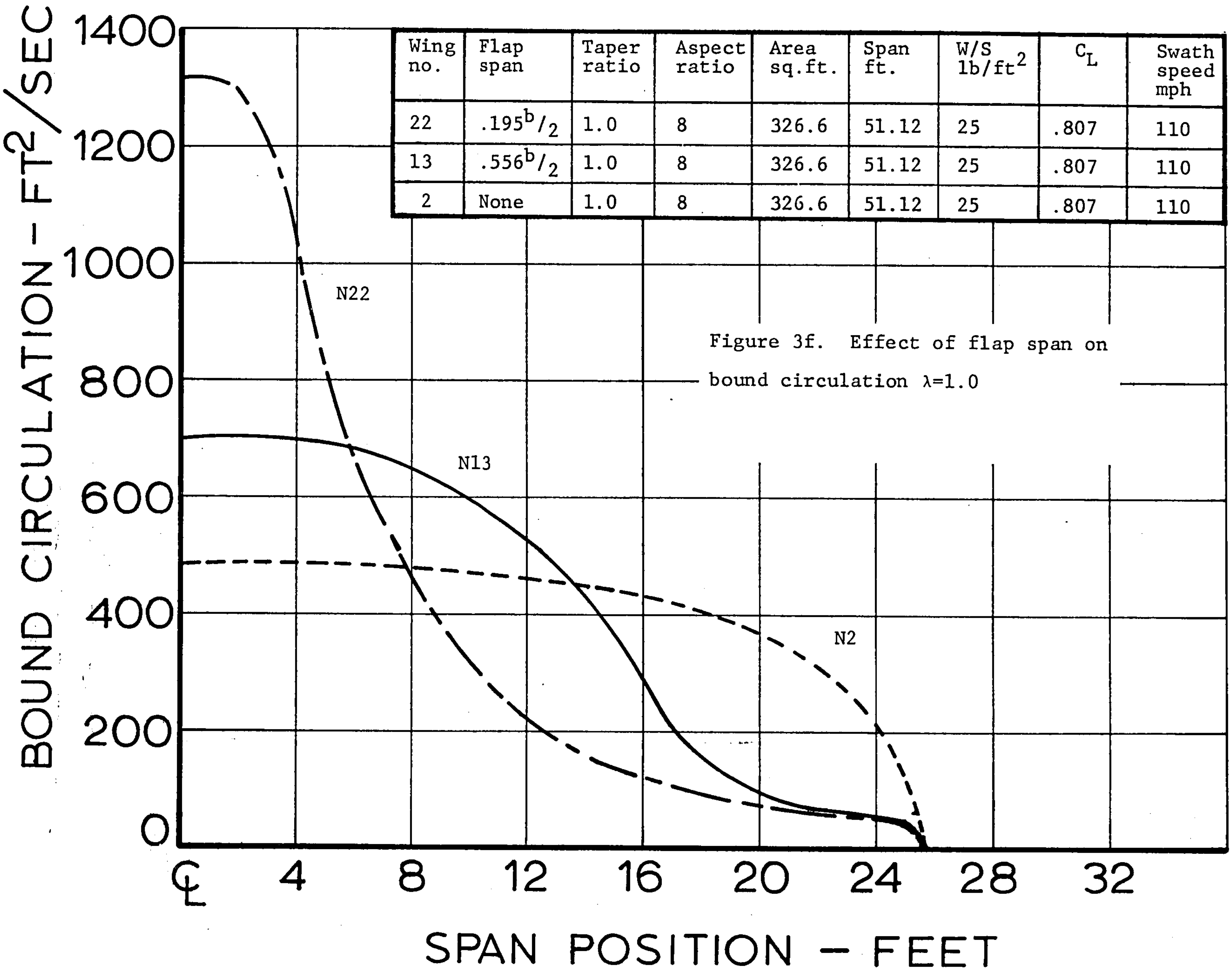
Figure 3d, Effect of taper ratio on bound circulation, S=450 sq.ft.

Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/sq.ft.	C_L	Swath speed mph
10	None	1.0	8.0	450	60	25	0.807	110
12	None	0.667	8.0	450	60	25	0.807	110



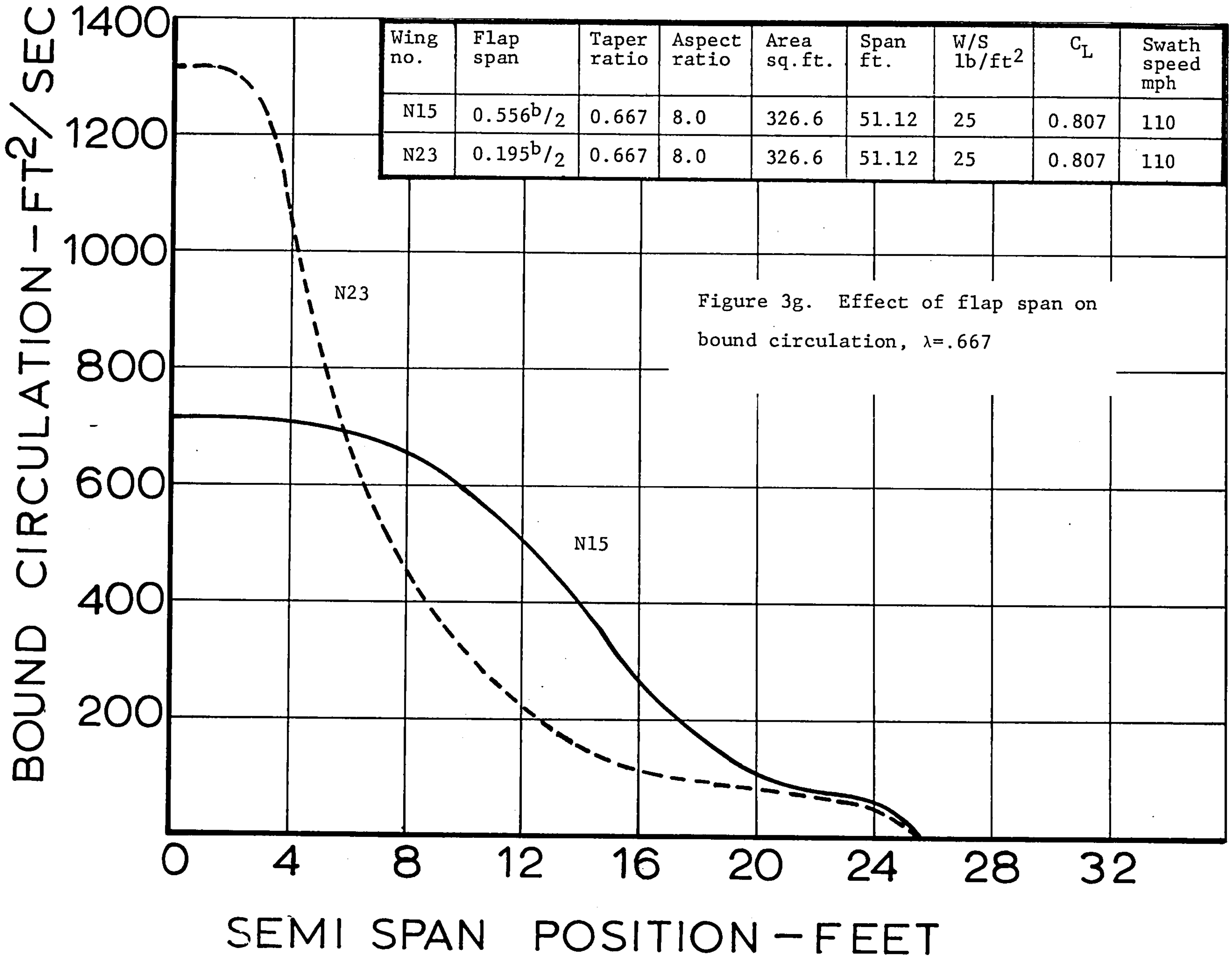
Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N13	0.556	1.0	8.0	326.6	51.12	25	0.807	110
N15	0.556	0.667	8.0	326.6	51.12	25	0.807	110

Figure 3e. Effect of taper ratio on bound circulation of wings with flaps.



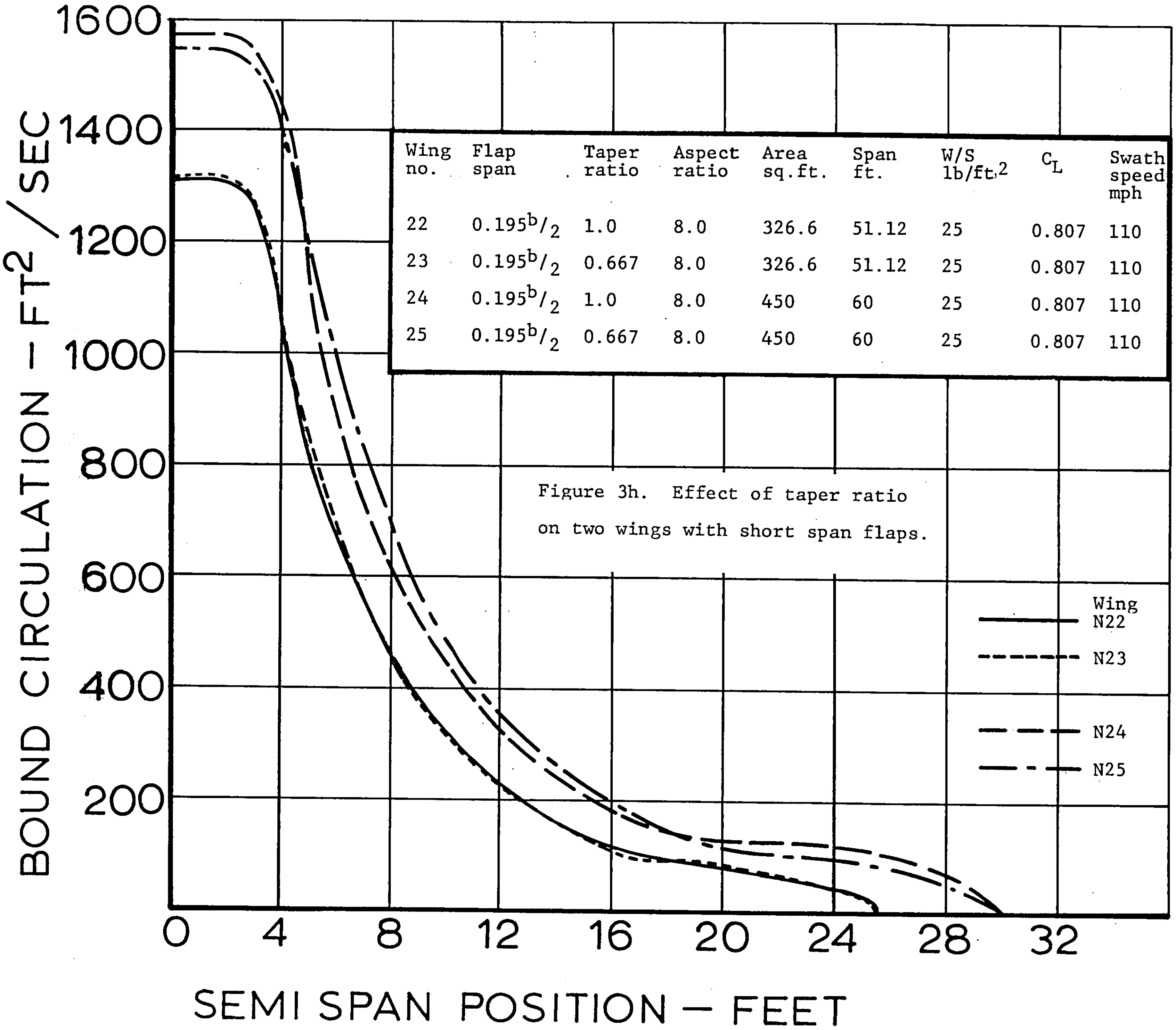
Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
22	$.195^b/_2$	1.0	8	326.6	51.12	25	.807	110
13	$.556^b/_2$	1.0	8	326.6	51.12	25	.807	110
2	None	1.0	8	326.6	51.12	25	.807	110

Figure 3f. Effect of flap span on bound circulation λ=1.0



Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N15	$0.556^{b}/_{2}$	0.667	8.0	326.6	51.12	25	0.807	110
N23	$0.195^{b}/_{2}$	0.667	8.0	326.6	51.12	25	0.807	110

Figure 3g. Effect of flap span on bound circulation, λ=.667



Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft.^{2}	C_L	Swath speed mph
22	$0.195^{b}/_{2}$	1.0	8.0	326.6	51.12	25	0.807	110
23	$0.195^{b}/_{2}$	0.667	8.0	326.6	51.12	25	0.807	110
24	$0.195^{b}/_{2}$	1.0	8.0	450	60	25	0.807	110
25	$0.195^{b}/_{2}$	0.667	8.0	450	60	25	0.807	110

Figure 3h. Effect of taper ratio on two wings with short span flaps.

Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N23	0.195	0.667	8.0	326.6	51.116	25	0.807	110
N21	0	0.667	8.0	326.6	51.116	25	0.807	110
N31	0.805*	0.667	8.0	326.6	51.116	25	0.807	110

* Outboard

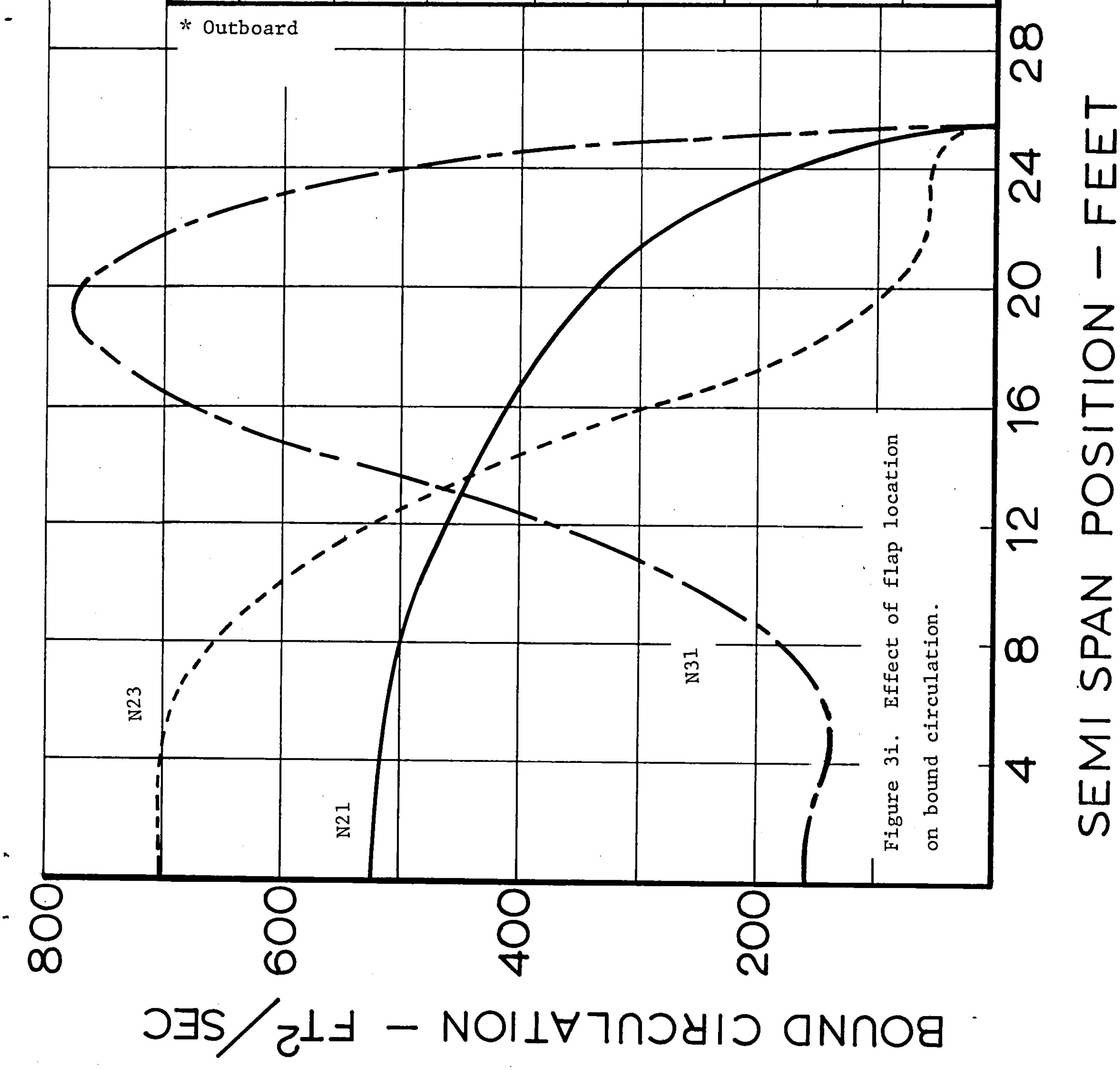
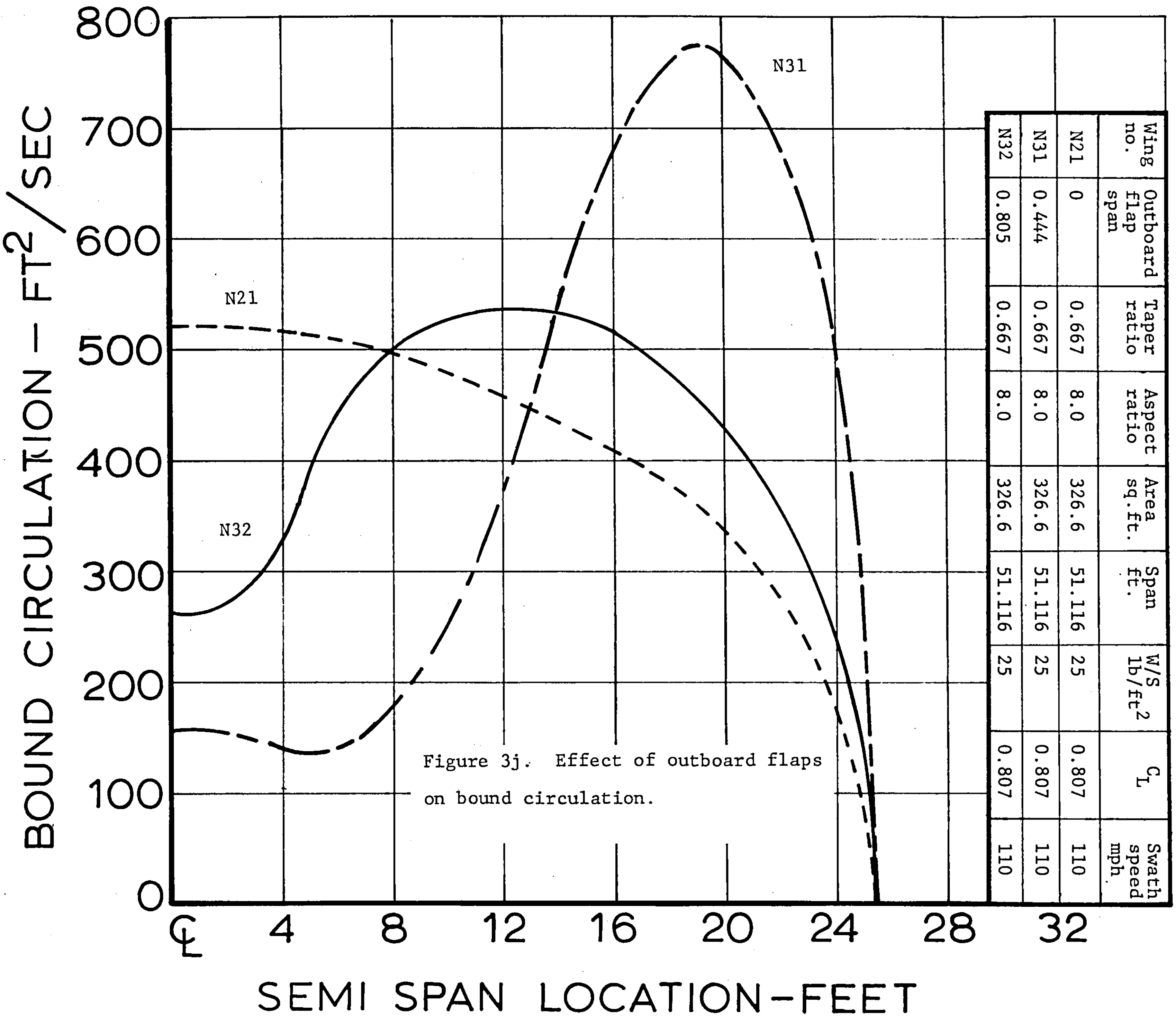
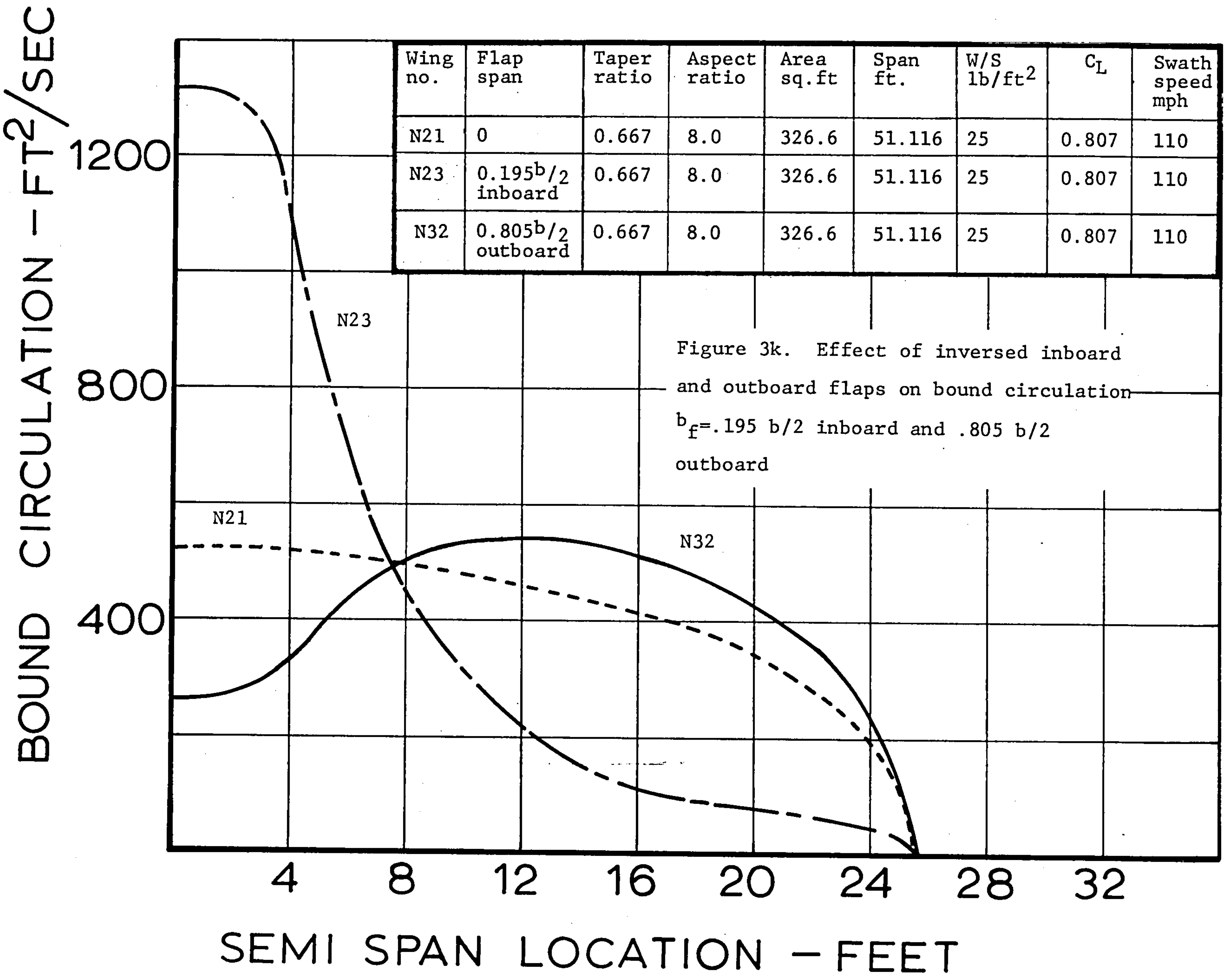


Figure 3i. Effect of flap location on bound circulation.



Wing no.	Outboard flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N21	0	0.667	8.0	326.6	51.116	25	0.807	110
N31	0.444	0.667	8.0	326.6	51.116	25	0.807	110
N32	0.805	0.667	8.0	326.6	51.116	25	0.807	110

Figure 3j. Effect of outboard flaps on bound circulation.



Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N21	0	0.667	8.0	326.6	51.116	25	0.807	110
N23	0.195b/2 inboard	0.667	8.0	326.6	51.116	25	0.807	110
N32	0.805b/2 outboard	0.667	8.0	326.6	51.116	25	0.807	110

Figure 3k. Effect of inversed inboard and outboard flaps on bound circulation b_f=.195 b/2 inboard and .805 b/2 outboard

Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N15	None	.667	8	326.6	51.12	25	.807	110
N21	.556$^b/_2$ inboard	.667	8	326.6	51.12	25	.807	110
N31	.444$^b/_2$ outboard	.667	8	326.6	51.12	25	.807	110

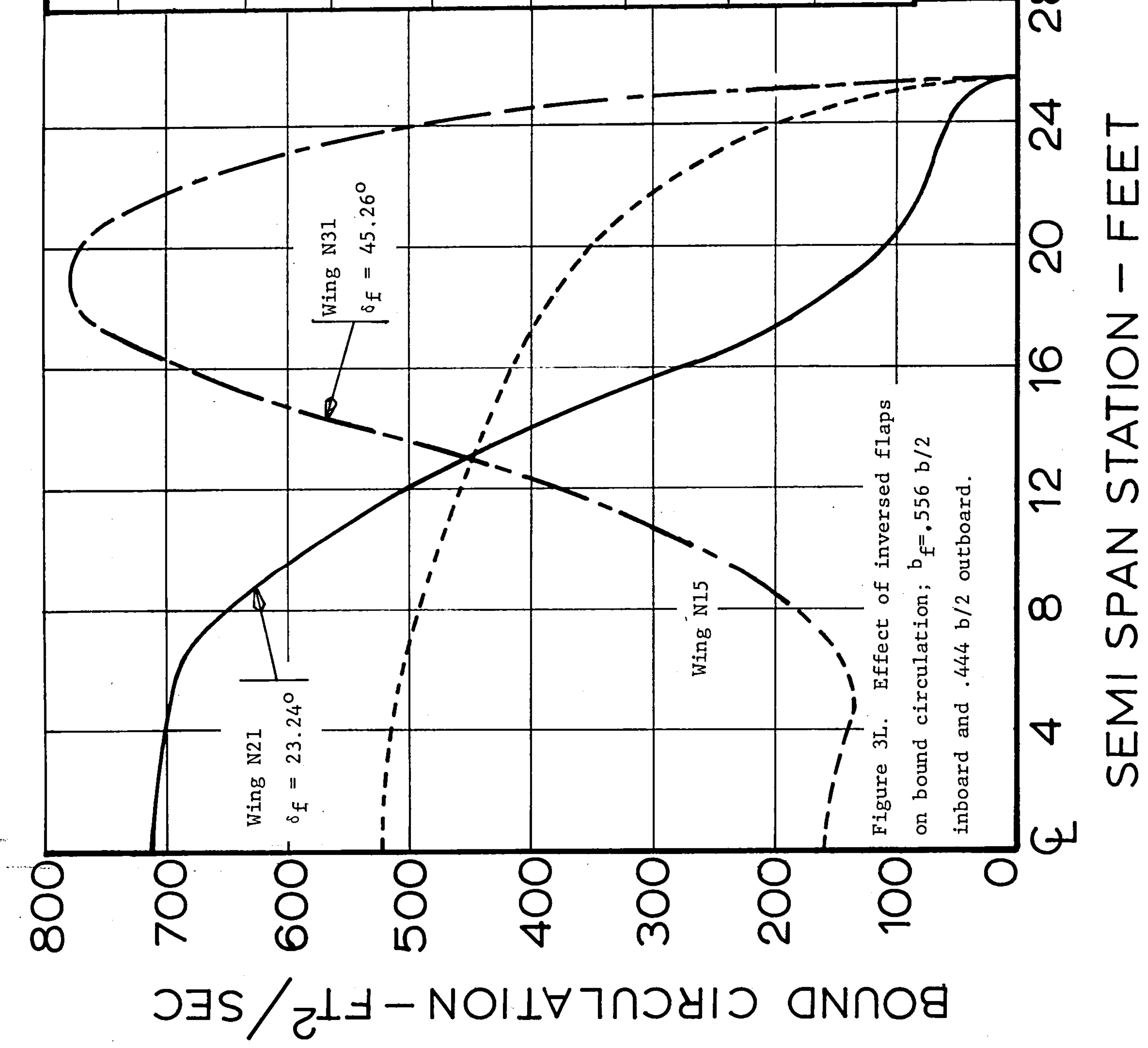


Figure 3L. Effect of inversed flaps on bound circulation; b_f=.556 b/2 inboard and .444 b/2 outboard.

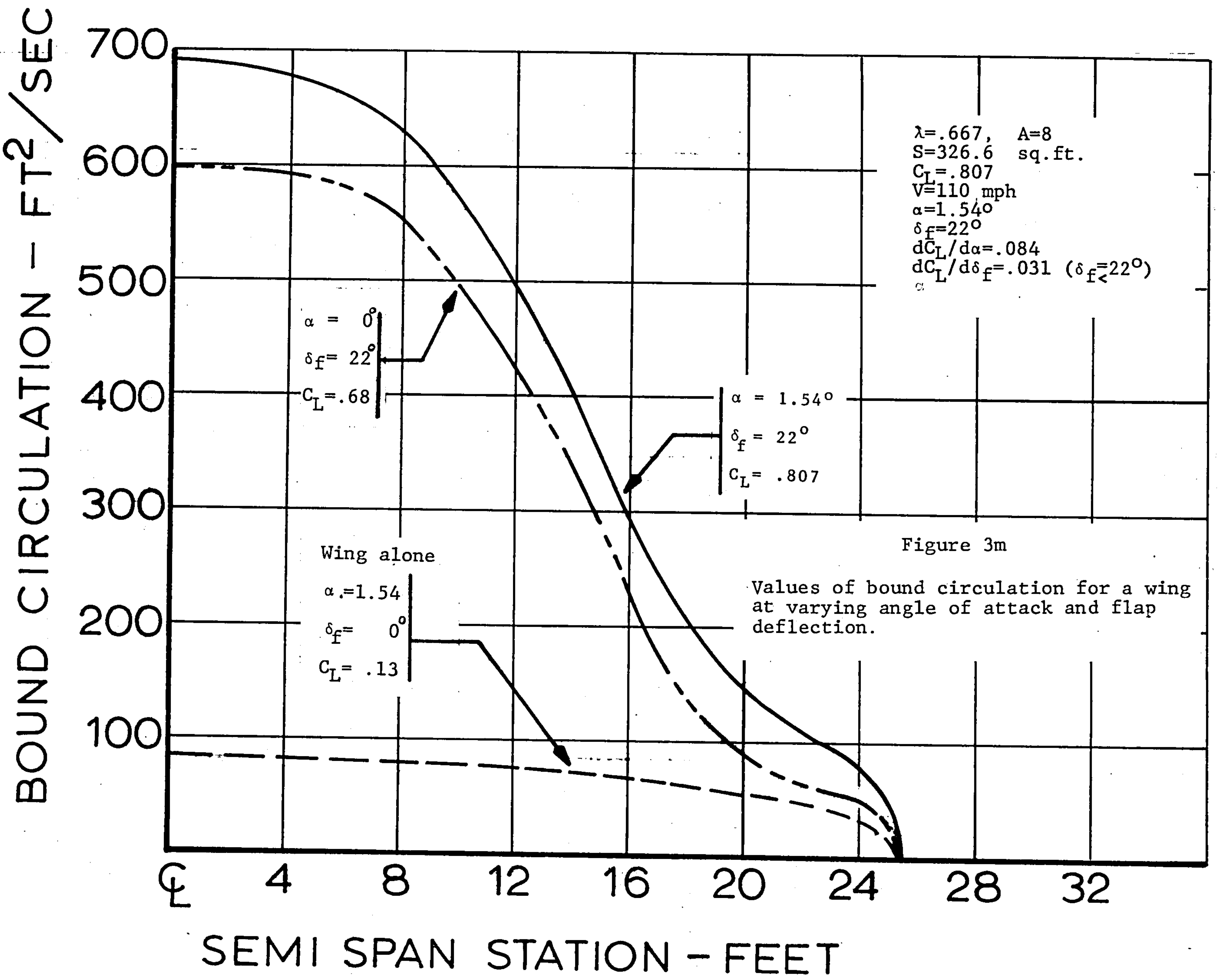


Figure 3m

Values of bound circulation for a wing at varying angle of attack and flap deflection.

Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
37	None	0.667	8	326.6	51.12	30	0.807	120
37A	None	0.667	8	326.6	51.12	30	0.97	110
39	None	0.667	8	326.6	51.12	40	0.807	139.3
39A	None	0.667	8	326.6	51.12	40	1.29	110

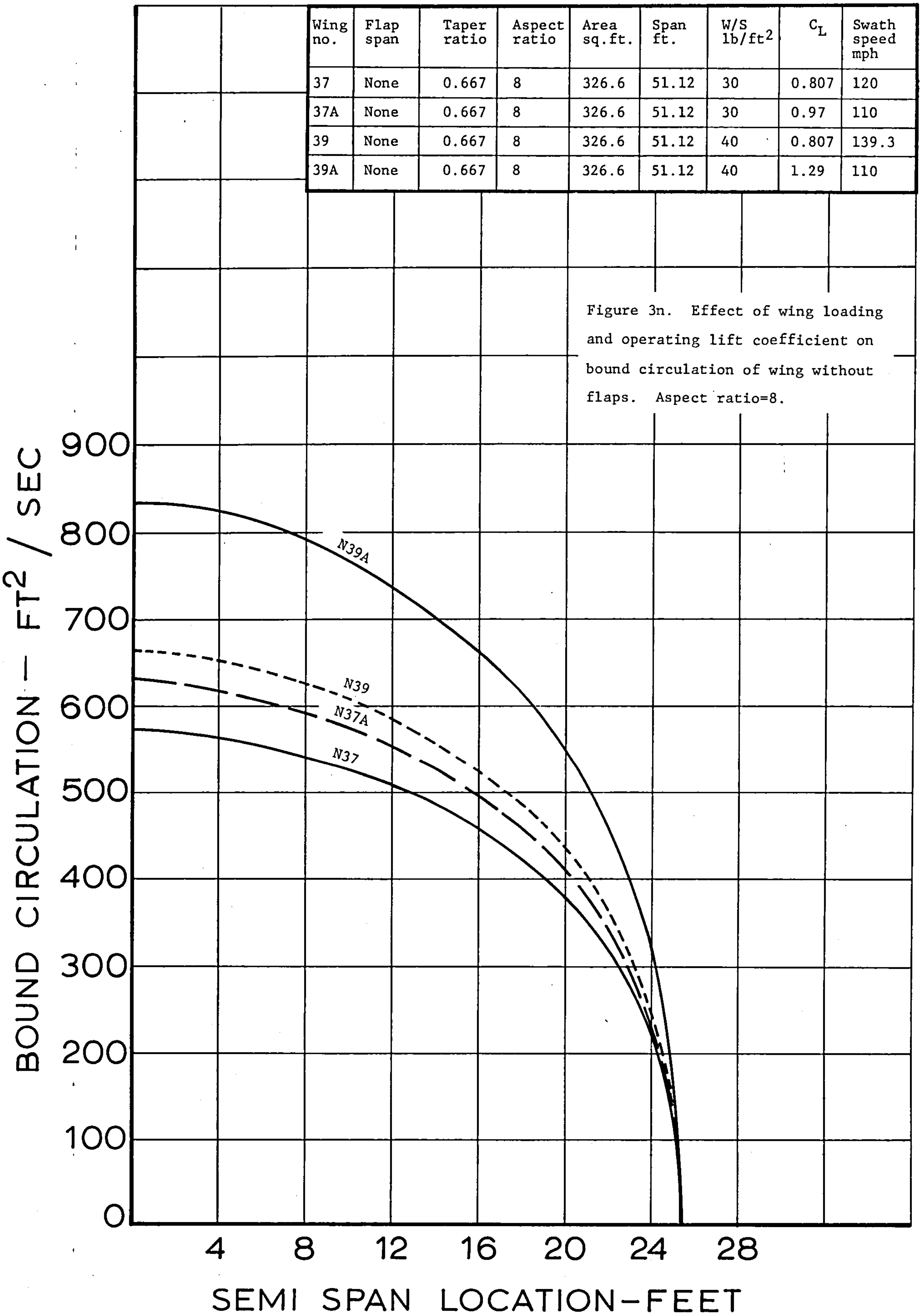
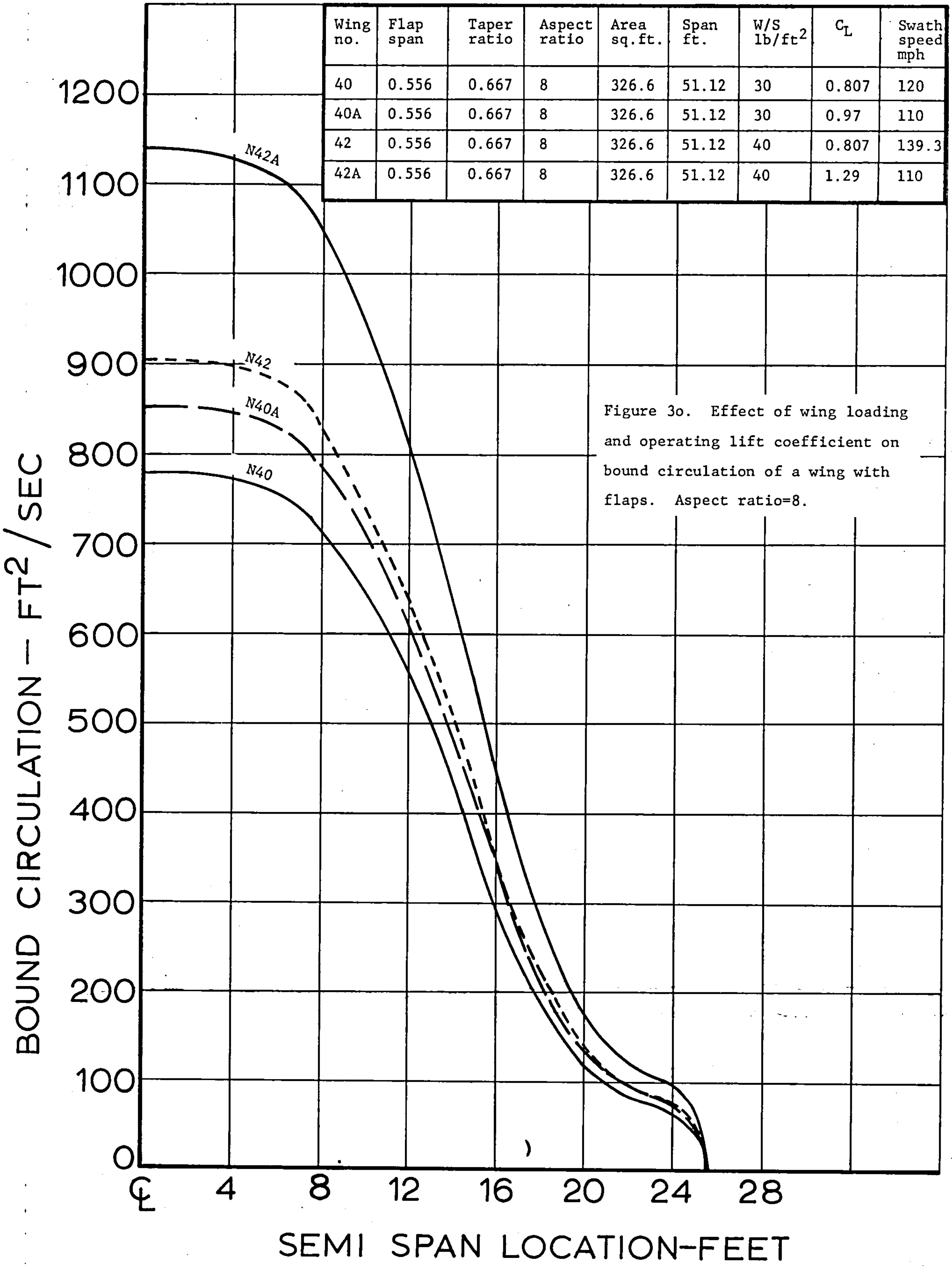


Figure 3n. Effect of wing loading and operating lift coefficient on bound circulation of wing without flaps. Aspect ratio=8.



Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
40	0.556	0.667	8	326.6	51.12	30	0.807	120
40A	0.556	0.667	8	326.6	51.12	30	0.97	110
42	0.556	0.667	8	326.6	51.12	40	0.807	139.3
42A	0.556	0.667	8	326.6	51.12	40	1.29	110

Figure 3o. Effect of wing loading and operating lift coefficient on bound circulation of a wing with flaps. Aspect ratio=8.

Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
43	None	0.667	6	326.6	51.12	30	0.807	120
43A	None	0.667	6	326.6	51.12	30	.97	110
45	None	0.667	6	326.6	51.12	40	0.807	139.3
45A	None	0.667	6	326.6	51.12	40	1.29	110

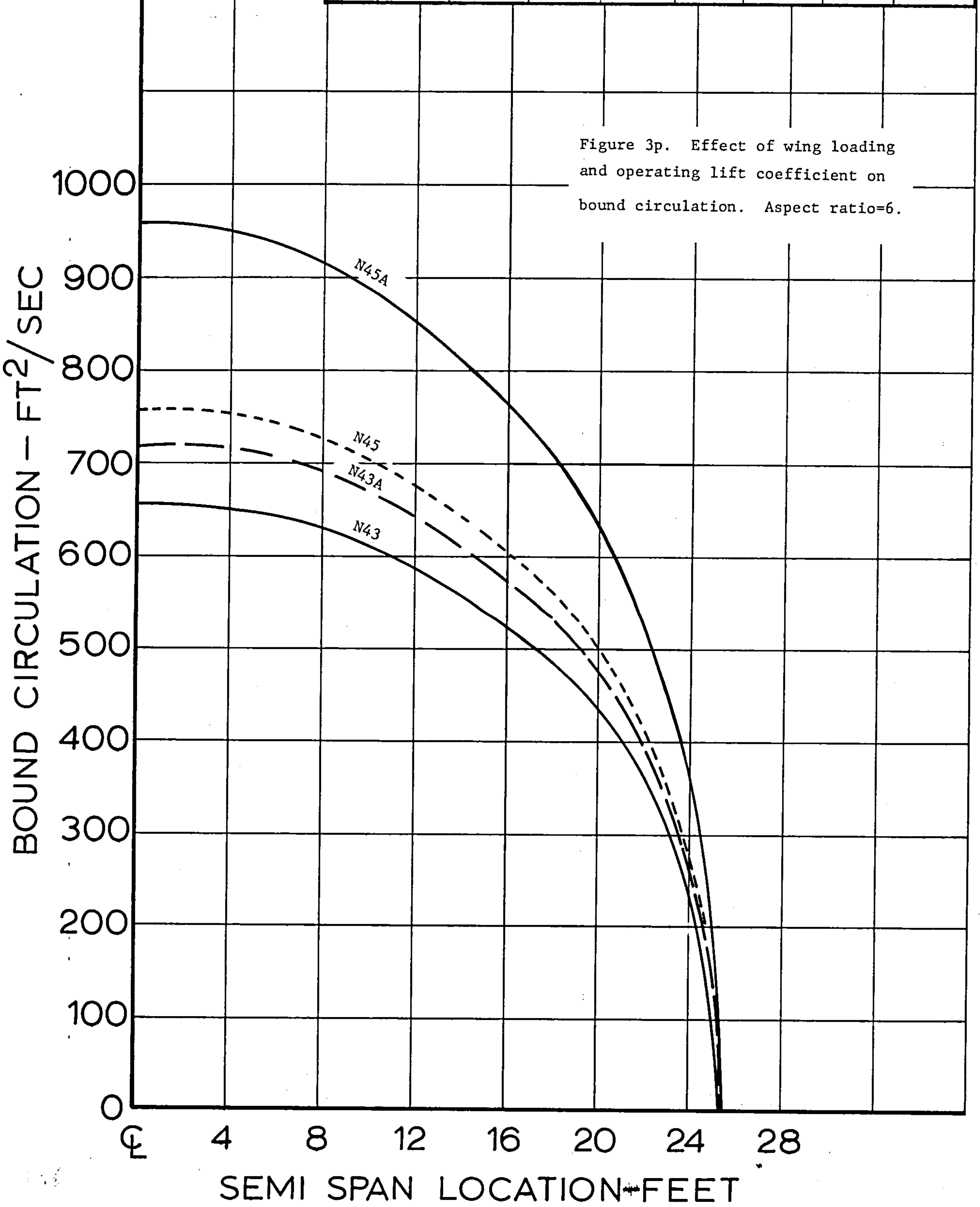
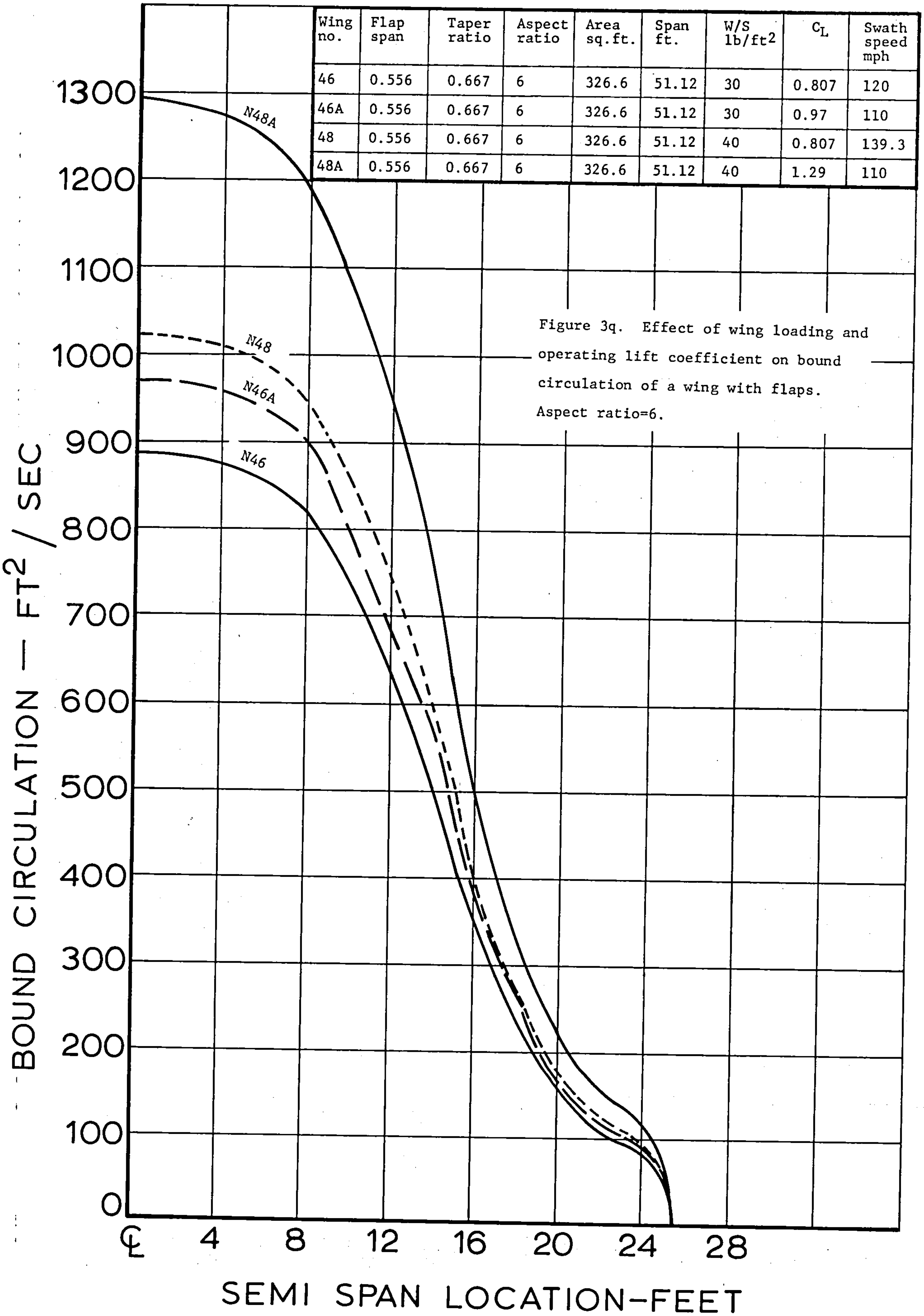
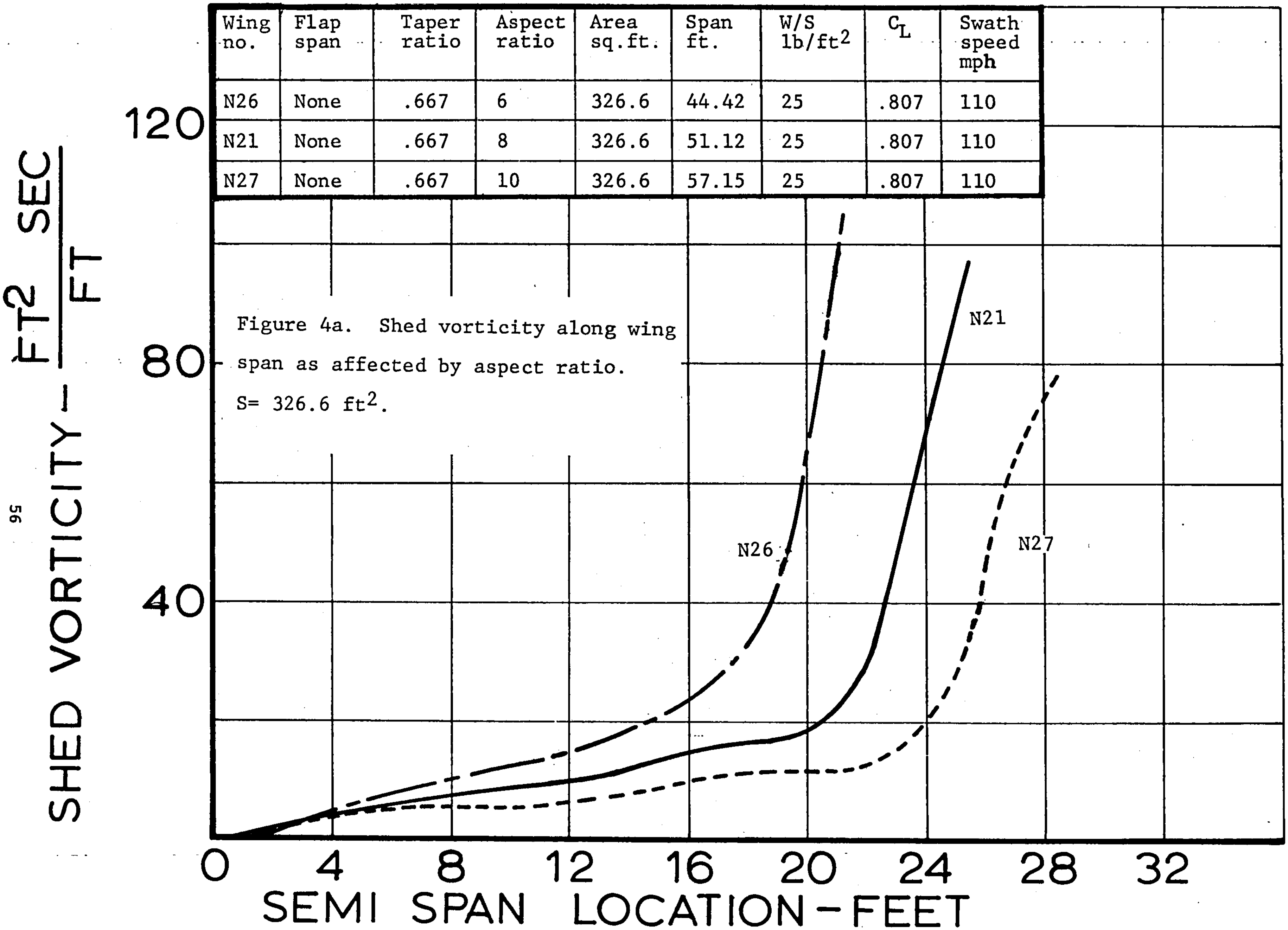


Figure 3p. Effect of wing loading and operating lift coefficient on bound circulation. Aspect ratio=6.



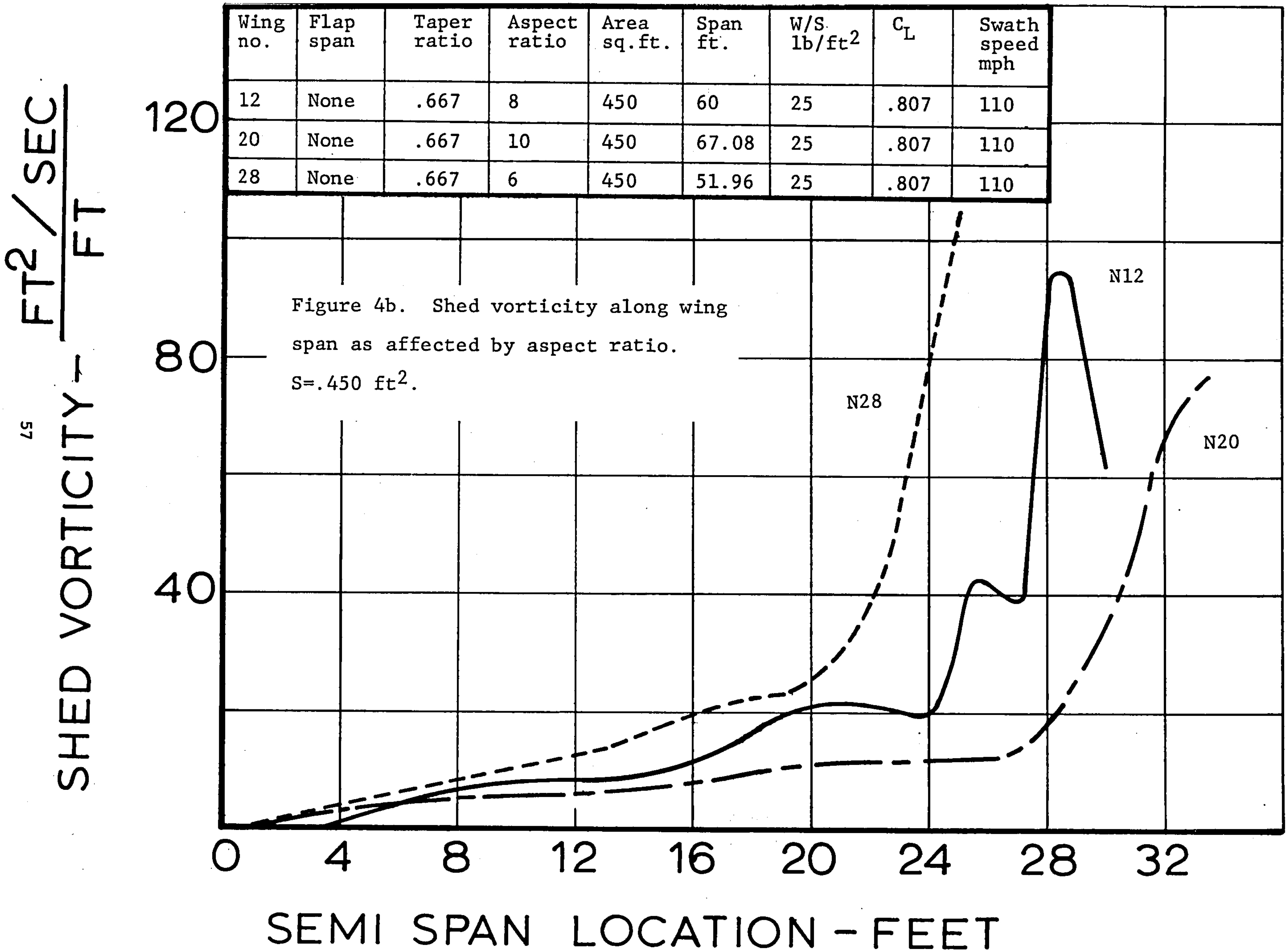
Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
46	0.556	0.667	6	326.6	51.12	30	0.807	120
46A	0.556	0.667	6	326.6	51.12	30	0.97	110
48	0.556	0.667	6	326.6	51.12	40	0.807	139.3
48A	0.556	0.667	6	326.6	51.12	40	1.29	110

Figure 3q. Effect of wing loading and operating lift coefficient on bound circulation of a wing with flaps. Aspect ratio=6.



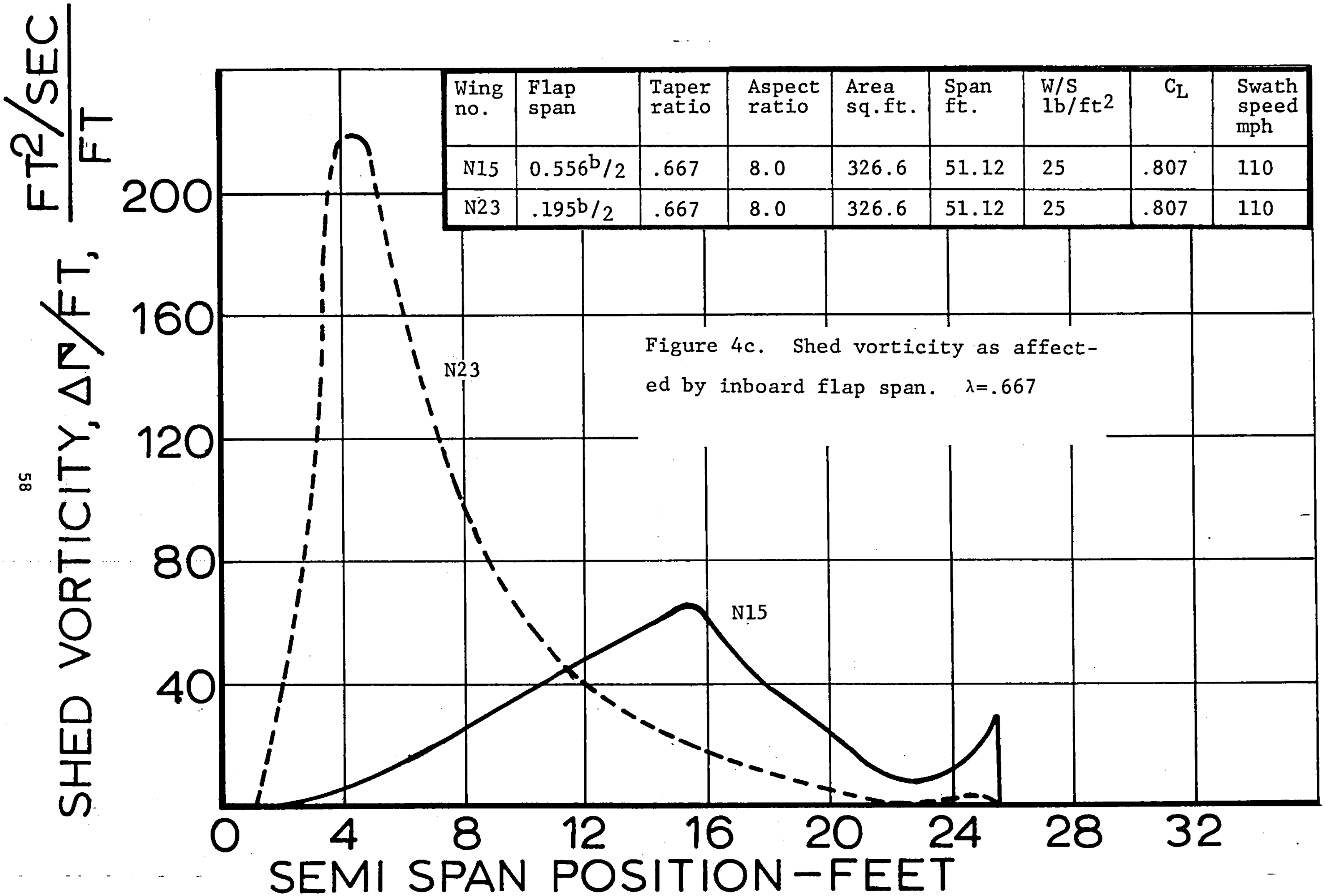
Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N26	None	.667	6	326.6	44.42	25	.807	110
N21	None	.667	8	326.6	51.12	25	.807	110
N27	None	.667	10	326.6	57.15	25	.807	110

Figure 4a. Shed vorticity along wing span as affected by aspect ratio. $S= 326.6\ ft^2$.



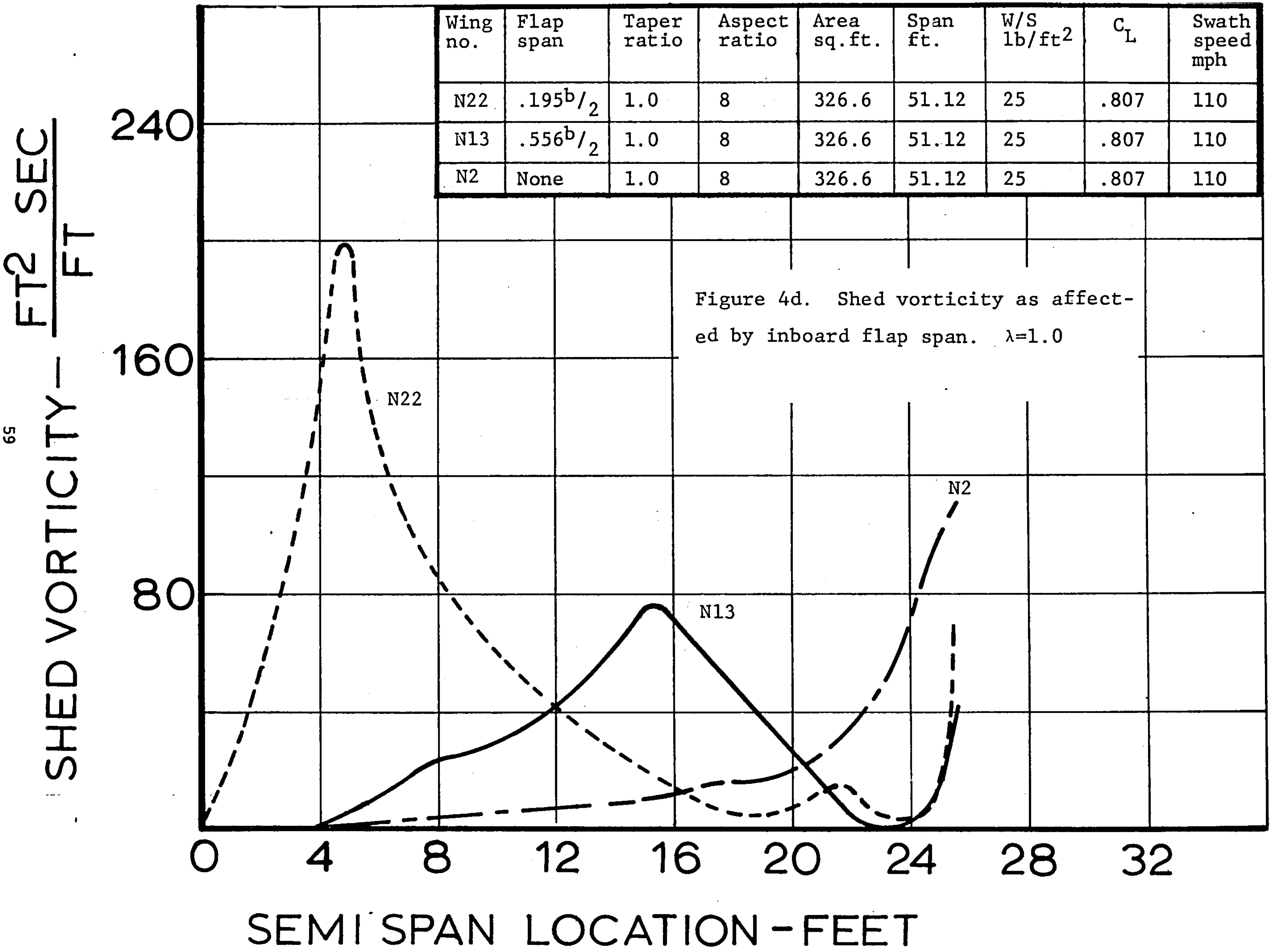
Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
12	None	.667	8	450	60	25	.807	110
20	None	.667	10	450	67.08	25	.807	110
28	None	.667	6	450	51.96	25	.807	110

Figure 4b. Shed vorticity along wing span as affected by aspect ratio. S=.450 ft^2.



Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N15	0.556b/2	.667	8.0	326.6	51.12	25	.807	110
N23	.195b/2	.667	8.0	326.6	51.12	25	.807	110

Figure 4c. Shed vorticity as affected by inboard flap span. λ=.667



Wing no.	Flap span	Taper ratio	Aspect ratio	Area sq.ft.	Span ft.	W/S lb/ft^2	C_L	Swath speed mph
N22	$.195^b/_2$	1.0	8	326.6	51.12	25	.807	110
N13	$.556^b/_2$	1.0	8	326.6	51.12	25	.807	110
N2	None	1.0	8	326.6	51.12	25	.807	110

Figure 4d. Shed vorticity as affected by inboard flap span. $\lambda=1.0$

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