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A CLASS II WEIGHT ASSESSMENT FOR THE IMPLEMENTATION OF COMMONALITY AND PRELIMINARY STRUCTURAL DESIGNS FOR THE FAMILY OF COMMUTER AIRPLANES

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PREPARED FOR: NASA GRANT NGT-~~8001~~ 80001

PREPARED BY: UNIVERSITY OF KANSAS
AE 790 DESIGN TEAM
JANUARY 1987

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Table of Symbols

Symbol	Definition	Dimension
A	Aspect ratio	-----
b	Wing span	ft
b_a	Aileron span	ft
b_f	Flap span	ft
b_t	Tire width	ft
c	Wing chord	ft
c	Wing mean geometric chord	ft
c_f	Flap chord	ft
c_f	Equivalent skin friction coefficient	-----
c_j	Specific fuel consumption	lbs/lbs/hr
C_D	Drag coefficient	-----
C_{Do}	Zero lift drag coefficient	-----
c_l	Section lift coefficient	-----
$c_{l\alpha}$	Section lift curve slope	1/rad
$c_{l\alpha f}$	Section lift curve slope with flaps down	1/rad
C_L	Lift Coefficient	-----
C_m	Pitching moment coefficient	-----
D	Drag	lbs
D_p	Propeller diameter	ft
D_t	Tire diameter	ft
d_f, D_f	fuselage diameter	ft
e	Oswald's efficiency factor	-----
E	Endurance	hours
f	Equivalent parasite area	ft^2
FAR	Federal Air Regulation	-----
g	Acceleration of gravity	ft/sec^2
h	Altitude	ft
i_w	Wing incidence angle	degrees
$k\Delta$	Sweep angle correction factor	-----
k_f	Correction factor for split flaps	-----
L	Lift	lbs
L/D	Lift-to-drag ratio	-----
l_f	Fuselage length	ft
l_{fc}	Fuselage cone length	ft
l_m	Dist. c.g. to main gear	ft
l_n	Dist. c.g. to nose gear	ft
M	Mach number	-----
n	Load factor	-----
nm	Nautical mile (6,076 ft)	nm
n_p	Number of propeller blades	-----
n_s	Number of struts	-----
N	Number of engines	-----
P	Power, horse-power	hp

P_{bl}	Blade power loading	hp/ft^2
q	Dynamic pressure	psf
R	Range	nm
R_n	Reynold's number	-----
RC	Rate of climb	fpm or fps
s	Distance	ft
S	Wing area	ft^2
SHP	Shaft horsepower	hp
S_{wet}	Wetted area	ft^2
S_{wf}	Flapped wing area	ft^2
t	Time	sec, min, hr
t/c	Thickness ratio	-----
T	Thrust	lbs
V	True airspeed	mph, fps, kts
V	Volume coefficient	-----
W	Weight	lbs
X_{ac}	Distance from l.e. c to aerodynamic center	
x, y, z	Distance from reference to a component c.g.	ft, in
x_v, x_h, x_c	Distance from c.g. to a.c. of a surface	ft, in
y_t	Engine-out moment arm	ft

<u>Greek Symbols</u>

α	angle of attack	deg, rad
β	sideslip angle	deg, rad
δ	control surface deflection	deg, rad
λ	taper ratio	-----
Λ	sweep angle	deg, rad
π	3.142	-----
Γ	dihedral angle	deg, rad
ρ	air density	slugs/ft
σ	air density ratio	-----
θ_{fc}	fuselage cone angle	deg, rad
ϕ	lateral ground clearance angle	deg, rad
θ	longitudinal ground clearance angle	deg, rad
θ_{lof}	lift-off angle	deg, rad
ϵ	Downwash angle	-----
ϵ_t	twist angle	deg, rad
η	spanwise station, fraction of the span	-----
ψ	lateral tip-over angle	deg, rad
γ	flight path angle	deg, rad
λ	bypass ratio	-----

<u>Subscripts</u>

a	aileron

A	approach
abs	absolute
cat	catapult
cl	climb
cr	cruise
crew	crew
crit	critical
c/2	semi-chord
c/4	quarterchord
des	design
dry	without fluids or afterburner
e	elevator
E	empty
f	flaps
ff	fuel fraction
F	mission fuel
FL	field length
guess	guessed
h	altitude
h	horizontal tail
le	leading edge
L	landing
LG	landing, ground
LO	lift-off
max	maximum
ME	manufacturer's empty
OE	operating empty
PA	power approach
PL	payload
RC	rate of climb
r	root
res	reserve
reqd	required
s	stall
TO	take-off
TOG	take-off, ground
t	tip
te	trailing edge
tent	tentative
tfo	trapped fuel and oil
used	used
w	wing
wet	wetted
wb	wing-body
wod	wind over the deck

Acronyms

AEO	All engines operating
APU	Auxiliary power unit
B.L.	Buttock line

c.g.	Center of gravity
F.S.	Fuselage station, Front spar
OEI	One engine inoperative
OWE	Operating weight empty
PAX	Passengers
p.d.	Preliminary design
R.S.	Rear Spar
sls	Sea level standard
TBP	Turboprop
W.L.	Waterline

1. INTRODUCTION

This report is completed in partial fulfillment of NASA-USRA Grant NGT-8001. The purpose of this report is to determine the feasibility of commonality objectives dictated in Reference 1. The feasibility of commonality will be discussed in terms of weight penalties that will increase the take-off weight of several members of the family of airplanes. Preliminary designs of fuselage structural members and a discussion of weight penalties due to implementation of common fuselage structure throughout the family is contained in Chapter 2.

Wing torque box designs along with structural weight penalties incurred are discussed in Chapter 3.

Chapter 4 contains a landing gear design study along with the weight penalties that a common gear system will impose.

Implementation of common powerplants throughout the family and the weight penalties that occur is the subject of Chapter 5.

Chapter 6 summarizes the weight penalties imposed by commonality on all the airplanes in the family. Class II weight breakdowns are also presented. The feasibility of commonality based on a percentage of take-off weight increase over the Class II baseline weights will then be assessed.

It should be noted that a complete assessment of the benefits or penalties of commonality cannot be realized until an operating cost and acquisition cost study is completed.

2. PRELIMINARY FUSELAGE STRUCTURAL DESIGN

The purpose of this chapter is to present the preliminary structural designs of fuselage bulkheads and stringers. Velocity-load factor diagrams for the commuter family are contained in Appendix A. The diagrams were used to help size structural components and compute Class II component weights due to ultimate loading conditions on the airplanes. Table 2.1 summarizes the limit load factors for the family of commuter airplanes.

Table 2.1 Limit Load Factors

Model	n_{lim}
25	2.87 (gust critical)
36	2.68
50	2.56
75	2.50
100	2.50

2.1 PRELIMINARY STRINGER SIZING

Using a method in Reference 2, the fuselage stringers were designed. Appendix B contains the calculations.

Twenty-four z-stringers are spaced equally around the fuselage. Table 2.2 summarizes the optimum stringer cross-sectional areas and weight per foot.

Table 2.2 Stringer Summary

Model	Area (in^2)	lbs/ft (Al 2024)	lbs/ft (ARALL)
25	.08	.097	.085
36	.13	.158	.138
50	.17	.206	.181

Table 2.3 shows that implementing the .17 in^2 stringer on all airplanes will cause fuselage weight penalties.

Table 2.3 Weight Penalty Due to Selection of .17 in ARALL Stringers

Model	l_f (fts)	optimum stringer wt. (lbs)	.17 in^2 stringer wt. (lbs)	W_{fus} due to stringer commonality (lbs)
25	69.4	142	302	160
36	78.1	259	339	80
50	94.6	411	411	0

2.2 PRELIMINARY BULKHEAD SIZING

A thickness of .06 in will be used for all fuselage frames that do not connect major structural components.

A .10 in thick frame will be used for pressure bulkheads, frames that connect wing spars, landing gear attachment points, engine mount attachments, etc. All airplanes in the family will use these frames. Weights of the frames are given in Table 2.4.

Table 2.4 Fuselage Bulkhead Weights

Material	.06 in frame	.10 in frame
Aluminum	10.1 lbs	16.8 lbs
ARALL	8.9 lbs	14.7 lbs

Using Aramid-Aluminum (ARALL), Table 2.5 summarizes the total bulkhead weight of each airplane in the family.

Table 2.5 ARALL Fuselage Bulkhead Weights

Model	No. of .06" frames	No. of .10" frames	Total bulkhead weight (lbs)	% W_{fus}
25	30	8	385	19.4
36	33	10	441	12.7
50	46	7	512	9.7
75	66	20	882	12.7
100	92	14	1024	9.7

Figure 2.1 contains the frame and stringer arrangement. The frame cross-section is also shown.

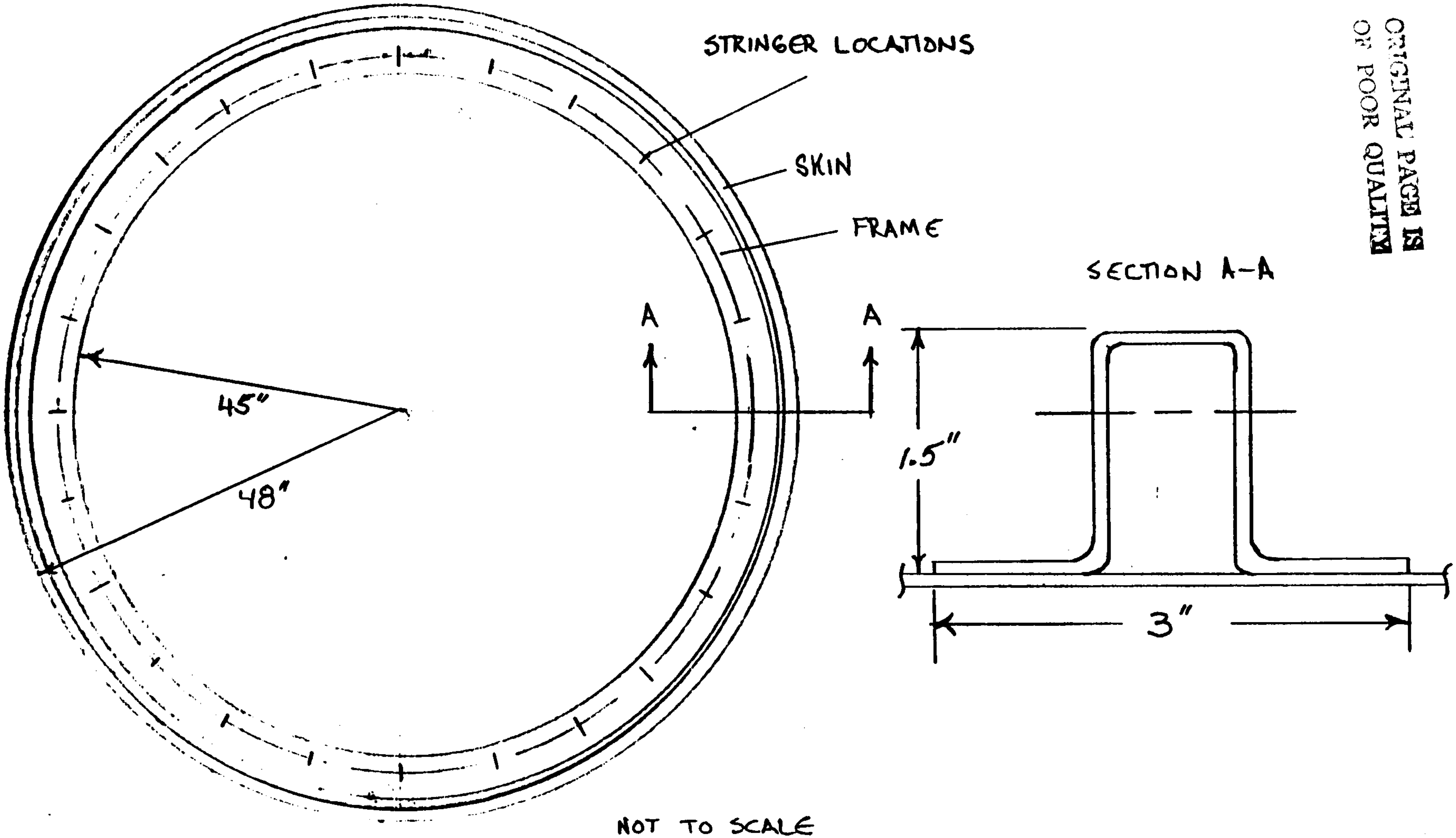

FIGURE 2.1 FUSELAGE BULKHEAD, STRINGER ARRANGEMENT

3. WING TORQUE BOX DESIGN

The purpose of this chapter is to present a common wing torque box design for the family of commuter airplanes. Figures 3.1 through 3.3 present wing cross sections with the common torque box arrangement shown.

3.1 WING SPAR SIZING

Using a method in Reference 2, the wing spars were sized from a maximum wing root bending moment. The required spar areas are listed in Table 3.1.

Table 3.1 Wing Spar Areas

Passenger Model	Spar Area (in^2)
25	4.21
36	7.26
50	10.8
75	7.26
100	10.8

Appendix C contains the wing spar sizing calculations.

This is where a design choice has to be made. It appears that the best solution for commonality and weight purposes would be to arrange the torque boxes as shown in Figures 3.1, 3.2, and 3.3. These torque boxes are arranged so that only one spar cap/stringer size (a standard 4 x 3.5 x 5/8 inch angle) is needed for all the airplanes. On the 25 passenger only four spar caps are needed as shown in Figure 3.1. On the 36 passenger 7 of these are needed. One possible way to arrange them is as shown in Figure 3.2. On the 50 passenger, 10 are needed; a possible arrangement is shown in Figure 3.3.

If no stringers were used, a highly concentrated load would be placed on the spar caps. Thus it appears more feasible to distribute the load on the 36 and 50 passenger airplanes as shown. There is no weight penalty involved if the torque boxes are designed in this manner.

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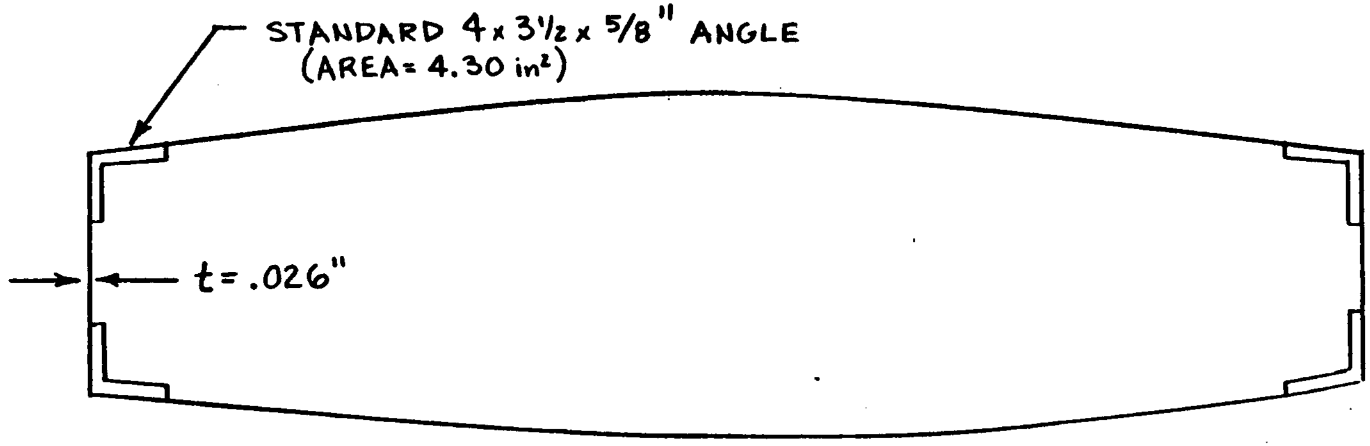

FIGURE 3.1 WING ROOT CROSS SECTION OF THE 25 PASSENGER COMMUTER

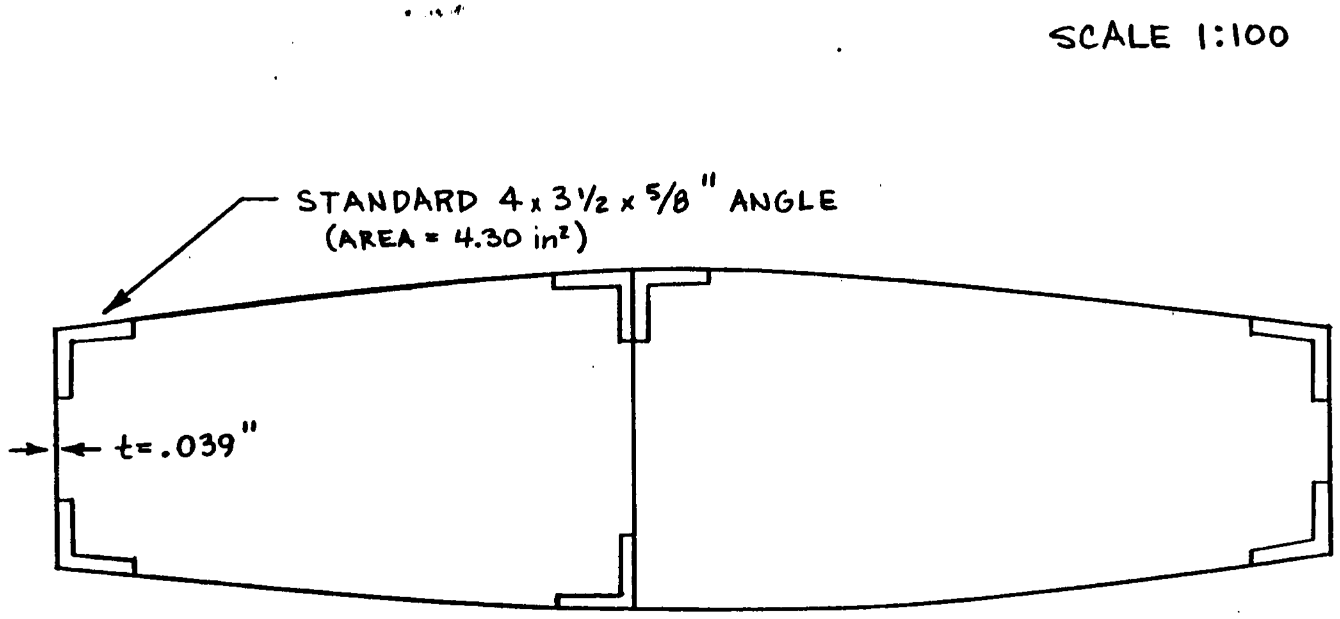

FIGURE 3.2 WING ROOT CROSS SECTION OF THE 36 PASSENGER COMMUTER

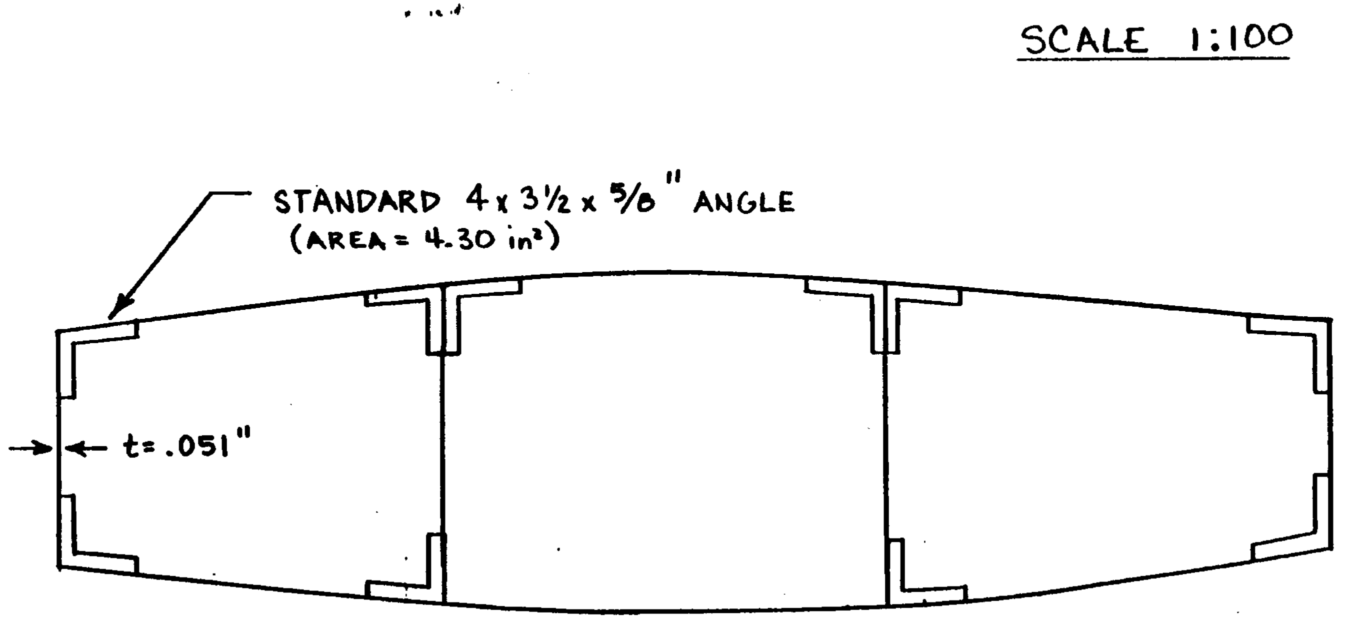

FIGURE 3.3 WING ROOT CROSS SECTION OF THE 50 PASSENGER COMMUTER

4. CLASS II LANDING GEAR DESIGN

The purpose of this chapter is to present the main gear strut and tire sizes for the commuter family landing gear. The landing gear weights are also presented and weight penalties due to implementing a common gear system is assessed. The Class II landing gear design work is contained in Appendix D. Table 4.1 contains the Class II tire sizes compared with the Class I results from Reference 1. Table 4.2 contains optimized shock absorber lengths and optimized strut diameters. Table 4.3 contains the optimized landing gear weights and presents the weight penalties for choosing a common gear. Table 4.4 summarizes the Class II landing gear design decisions.

Table 4.1 Tire Sizes for the Commuter Family

Pax Model	Class I Nose & Main D x W (in)	Class II Nose D x W (in)	Class II Main D x W (in)
25	30 x 6	16 x 4.4	29 x 11
36	30 x 6	18 x 4.4	26 x 11
50	30 x 6	17.5 x 6.0	31 x 13
75	30 x 6	18 x 5.5	26 x 11
100	30 x 6	18 x 5.5	31 x 13

Table 4.2 Shock and Strut Sizing for the Commuter Family

Pax Model	Optimized Shock Length (in)	Optimized Strut Area (in^2)
25	17.3	3.8
36	15.6	4.7
50	16.3	5.3
75	16.3	4.5
100	16.1	5.2

Table 4.3 Class II Landing Gear Weights

Model	Optimized Gear Weights Nose	Optimized Gear Weights Main	Common Gear Weights Nose	Common Gear Weights Main	Weight Penalty Nose	Weight Penalty Main	Weight Penalty Total	Weight Penalty % W_{TO}
25	201	765	331	1438	130	673	803	3.8
36	267	1097	331	1438	64	341	405	1.3
50	331	1438	331	1438	0	0	0	0
75	437	2036	662	2876	225	840	1065	1.7
100	499	2684	662	2876	163	192	355	0.4

Table 4.4 Class II Landing Gear Summary

Nose Gear Tire	18" x 5.5"
Main Gear Tire	18" x 5.5"
Shock Absorber Length	17.3 in
Strut Diameter	4.7 in

The weight penalties imposed by implementing a common landing gear system on all family members are particularly substantial on the 25 passenger model (3.8% of W_{TO}). The production economics of this common gear arrangement should be studied before determining completely the feasibility of a common gear arrangement.

5. POWERPLANT COMMONALITY STUDY

The purpose of this chapter is to determine the weight penalties due to the selection of common powerplants.

Table 5.1 presents powerplant weights for the commuter family. Optimized powerplant weights are compared to the weight of the powerplants selected for commonality purposes. Powerplant component weights were calculated from Reference 5. Powerplant weight breakdowns are contained in Appendix E. Reference 1 stated that a 6000 shp engine would power the 25, 36, and 50 passenger models, and a 13,500 shp engine would power the 75 and 100 passenger models.

The 13,500 shp engine was necessary to power the conventionally configured 75 and 100 passenger models presented in Reference 1. Use of the twin-body concept for the 75 and 100 passenger models allows for a lighter take-off weight and a reduction in required engine shaft horsepower to an 11,000 shp model. A 5500 shp engine for use in the 25, 36, and 50 passenger models would reduce the weight penalty due to commonality for these airplanes. Using these smaller shp engines, the greatest weight penalty due to powerplant commonality is 2.8% of the 25 passenger take-off weight (583 lbs).

Table 5.1 Summary of Powerplant Weight Study

Model	25	36	50	75	100
SHP_{req}	4210	4485	5500	9000	11000
SHP_{eng}	5500	5500	5500	11000	11000
optimum* W_{PWR}	5274	5422	5898	11811	12862
actual* W_{PWR}	5857	5883	5898	12838	12862
W_{PWR}	583	461	0	1027	0
% W_{TO}	2.77	1.47	0	1.69	0

* Includes: Engine, Gearbox, Nacelle, Propeller, Oil System, Fuel System

Actual W_{PWR} are different due to different size fuel systems.

6. CLASS II WEIGHT BREAKDOWNS

The purpose of this chapter is to present the Class II component weights for the family of commuter airplanes. Table 6.1 contains the baseline component weight breakdown for the commuter family. Table 6.2 contains component weight breakdowns with the following commonality objectives and corresponding weight penalties, including:

1) Common Fuselage Structure
2) Common Wing Torque Box
3) Common Landing Gear System
4) Common Powerplants
5) Common Fixed Equipment Weights

Table 6.3 summarizes the Class II weights and documents the take-off weight penalties that commonality imposed. All airplane component weights were calculated from Reference 6. The component weights contained in Tables 6.1 through 6.3 have been calculated from the Class I take-off weights. No iterating to converge on a Class II take-off weight was completed. The 25 and 100 passenger models may require weight iterating.

Table 6.3 shows the greatest penalty suffered due to the implementation of commonality occurs on the 25 passenger model. The weight penalty is 1546 lbs., or 6.6% of the Class II baseline take-off weight. This weight penalty appears acceptable. The direct operating cost increase will need to be evaluated before a final decision on commonality can be made.

Table 6.1 Baseline Component Empty Weight Breakdowns

Model	25	36	50	75	100
W_W	1587	1975	2899	3068	4349
W_{EMB}	267	267	267	488	488
$W_{V.T.}$	281	307	340	614	680
$W_{H.T.}$	125	125	200	1027	1027
W_{FUS}	1982	3483	5278	6966	10556
W_{AT}	1585	1585	1585	3170	3170
$W_{M.G.}$	765	1097	1438	2036	2684
$W_{N.G.}$	201	267	331	437	499
W_{STRUCT}	6793	9106	12338	17806	23453
W_{PWR}	5274	5422	5898	11811	12862
W_{ec}	34	37	37	44	44
W_{ess}	27	27	27	91	91
W_{fc}	429	729	873	1458	1746
W_{hps}	189	283	379	546	726
W_{els}	735	846	944	1103	1253
W_{aei}	445	555	658	843	1016
W_{apsi}	535	878	1092	1755	2183
W_{ox}	66	82	102	164	204
W_{fur}	1358	1995	2535	3969	4952
W_{APU}	60	60	60	120	120
W_{pt}	105	157	210	314	421
W_{FEQ}	3983	5649	6917	10407	12756
W_E	16050	20177	25153	40024	49071

Table 6.2 Class II Component Empty Weight Breakdown with Commonality Objectives Implemented

Model	25	36	50	75	100
W_W	2899	2899	2899	4349	4349
W_{EMB}	267	267	267	488	488
$W_{V.T.}$	340	340	340	680	680
$W_{H.T.}$	200	200	200	1027	1027
W_{FUS}	2158	3575	5278	7150	10556
W_{AT}	1585	1585	1585	3170	3170
$W_{M.G.}$	1438	1438	1438	2876	2876
$W_{N.G.}$	331	331	331	662	662
W_{STRUCT}	9218	10635	12338	20402	23808
W_{PWR}	5434	5434	5434	12196	12196
W_{FS}	464	464	464	666	666
W_{ec}	34	37	37	44	44
W_{ess}	27	27	27	91	91
W_{fc}	429	729	873	1458	1746
W_{hps}	189	283	379	546	726
W_{els}	735	846	944	1103	1253
W_{aei}	445	555	658	843	1016
W_{apsi}	535	878	1092	1755	2183
W_{ox}	66	82	102	164	204
W_{fur}	1358	1995	2535	3969	4952
W_{APU}	60	60	60	120	120
W_{pt}	105	157	210	314	421
W_{FEQ}	4447	6113	7381	11073	13422
W_E	19099	22182	25153	43671	49426

Table 6.3a Summary of Class II Baseline Weights

Model	25	36	50	75	100
W_{TO}	25457	33949	43141	67772	84689
W_E	16050	20177	25153	40024	49071
W_{PL} + CREW	5535	7995	10865	16195	21320
W_{tfo}	105	157	210	313	420
W_F	3767	5620	6913	11240	13878

Table 6.3b Summary of Class II Weights Implementing Commonality

W_{TO}	28506	35954	43141	71419	85044
W_E	19099	22182	25153	43671	49426
ΔW_{TO}	3049	2005	0	3647	355
% Change Above Baseline W_{TO}	12.0	5.9	0	5.4	0.4

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

1) The proposed multi-spar arrangement for the wing torque box does not impose structural weight penalties for the family of commuter airplanes.

2) Implementing commonality objectives caused take-off weight penalties summarized in Table 7.1.

3) The degree to which take-off weight can be penalized due to implementing commonality must be determined.

Table 7.1 Weight Penalty Imposed By Commonality Over Class II Baseline

Model:	25	36	50	75	100
ΔWW	1312	924	0	1281	0
ΔWFUS	176	92	0	184	0
ΔWEMP	134	108	0	66	0
ΔWL.G.	803	405	0	1065	355
ΔWPWR	624	476	0	1051	0
ΔWTO	3049	2005	0	3647	355
% Diff. over Class II baseline	12.0	5.9	0	5.4	0.4

7.2 Recommendations

1) The performance degradation due to the take-off weight increase over the baseline needs to be evaluated.

2) Cost savings due to implementing commonality into the designs of the airplanes should be evaluated and compared with Class II baseline costs.

3) A Class II weight and balance should be completed. This should be finished before any more stability and control work is finished.

4) An attempt should be made to use just two different empennage designs.

5) A SSSA flight controller should be designed.

6) The Class II drag polars should be evaluated.

7) The roll performance should be checked, particularly that of the twin-body configurations.

8) The installed characteristics of the propulsion systems need to be evaluated.

9) Propellors need to be designed.

10) The Class II design work must be integrated into the Class I baselines.

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Appendix A
V-n Diagrams

A.1 INTRODUCTION

THE PURPOSE OF THIS APPENDIX IS TO PRESENT THE CLASS I V-n DIAGRAMS FOR THE FAMILY OF COMMUTER AIRPLANES.

THE METHOD USED TO CALCULATE THE V-n DIAGRAMS IS CONTAINED IN CH. 4 OF REFERENCE 6.

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A.4	50 PAK V-n DIAGRAM	A.11
A.5	75 PAK V-n DIAGRAM	A.15
A.6	100 PAK V-n DIAGRAM	A.19

Step 1. Determine V_{S_1}

From Eqn 4.19

$GW/S = 21046/421$

$V_{S_1} = [2(GW/S)/\rho C_{N_{max}}]^{1/2}$

$GW/S = 50$ psf.

$GW = W_{TO} = 21046$ lb $\rho = .002377$ slug/ft³

$S = 421$ ft²

by (4.6) $C_{N_{max}} = 1.1\, C_{L_{max}}$ $C_{L_{max}} = 1.4$

$C_{N_{max}} = 1.54$

$V_{S_1} = [2(21046/421)/(.002377)(1.54)]^{1/2}$

$V_{S_1} = 165.27$ ft/sec $= 98.0$ knts.

$V_{S_1} = 98$ knts

Step 2. Determination of V_A

From (4.22) $V_A \geq V_{S_1}\, n_{lim}^{1/2}$

From (4.23) $n_{lim_{pos}} \geq 2.1 + 24000/(W + 10000)$

$n_{lim_{pos}} \geq 2.1 + 24000/(21046 + 10000)$

$n_{lim_{pos}} \geq 2.87$

Thus from (4.22) $V_A \geq (165.27)(2.87)^{1/2} = 279.985$ fps

$V_A \geq 166$ knts

Step 3 Gust Load Factor Lines

$\bar{c} = 6.28$ ft. $C_{L_\alpha} = 4.71$ rad^{-1}

Eqn (4.18) $\mu_g = 2(GW/S)/\rho \bar{c}\, g\, C_{L_\alpha}$

$\mu_g = 2(50)/(.002377)(6.28)(32.2)(4.71)$

$\mu_g = 44.17$

From Eqn (4.17) $K_g = .88\,\mu_g/(5.3 + \mu_g) = .88(44.17)/(5.3 + 44.17)$

$K_g = .7857$

Eqn (4.16) $n_{lim} = 1 + (K_g\, U_{de}\, V\, C_{L_\alpha})/498(GW/S) = 1 + (.786)(U_{de}\, V)(4.71)/498(50)$

$n_{lim} = 1 + .0001487\, U_{de}\, V$

V_B Line

0 - 20 000 ft. $U_{de} = 66$ fps

at 30,000 ft $U_{de} = 47.33 - .000933(30000) = 19.34$ fps.

Use $U_{de} = 66$ fps.

$n_{lim} = 1 + .00981\,V$

V_C line

0 - 20 000 ft $U_{de} = 50$ fps

at 30 000 ft $U_{de} = 66.67 - .000833(30000) = 41.68$ fps.

Use $U_{de} = 50$ fps.

$n_{lim} = 1 + .00744\,V$

V_D Line

0 - 20 000 ft $U_{de} = 25$ fps

at 30 000 ft $U_{de} = 16.67 - .000417(30\,000) = 4.16$ fps.

Use $U_{de} = 25$ fps.

$n_{lim} = 1 + .00372\,V$

Step 4, V_B

V_B is at intersection of $C_{N_{max}}$ line and V_E gust line.

From the Figure, this is determined to be, $V_E = 160$ knts.

Step 5, V_C

From Eqn (4.20) $V_C = V_B + 43$ knts

$V_C = 160 + 43 = 203$ knts.

However, mission spec calls for cruise speed $M = .7$ at 30 000 ft. This is 412 knts at 30 000 ft. or $\bar{q} = 216$ psf. At sealevel, the KEAS is 252 knts. Because this is larger,

$V_C = 252$ knts

Step 6, V_D

From Eqn (4.21) $V_D = 1.25 V_c = 1.25(252)$

V_D = 315 knts

Step 7 Negative Stall Line

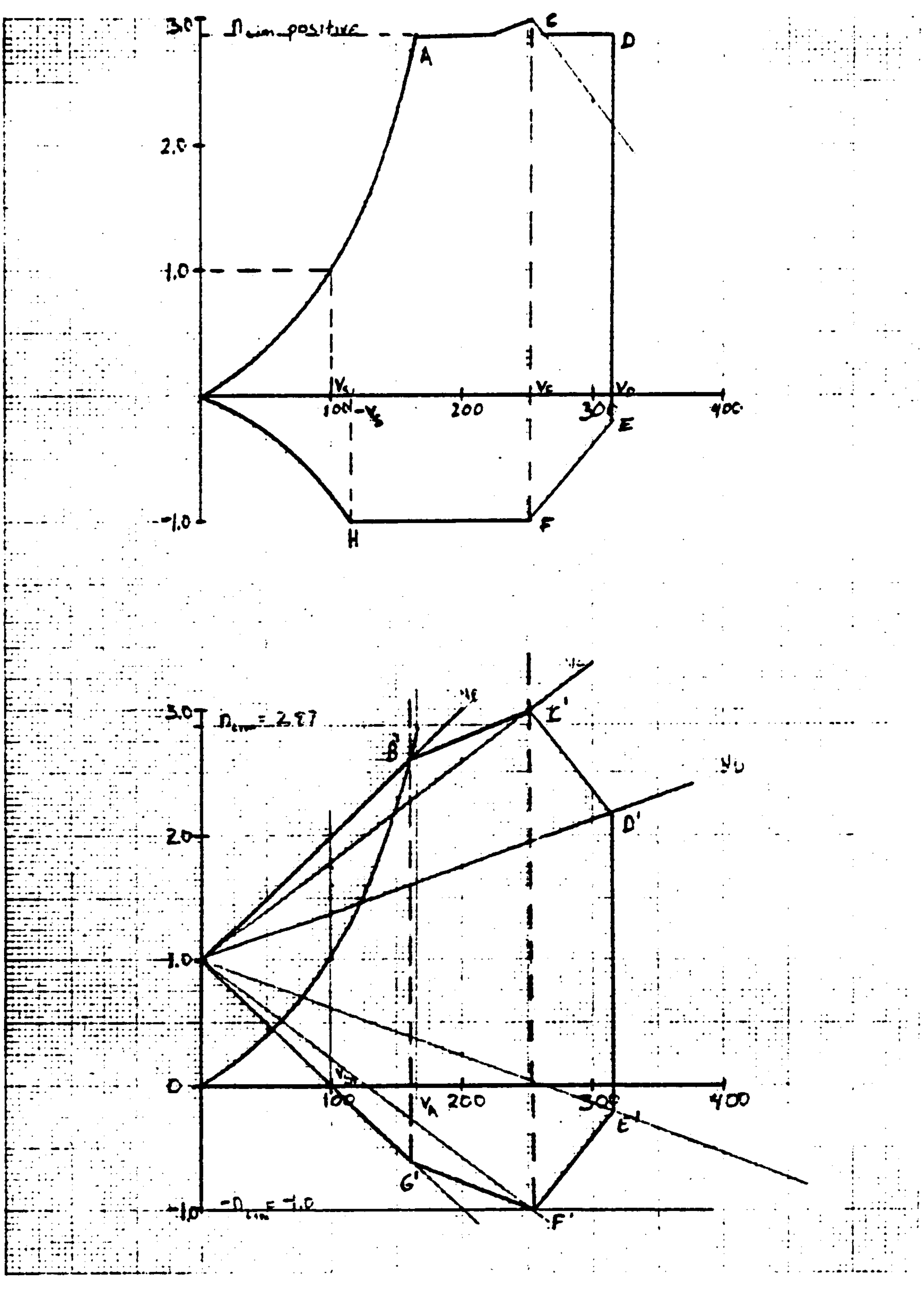
Assume $C_{L_{max_{neg}}} = -1.0$ $C_{n_{max_{neg}}} = -1.1$

Eqn (4.4) $V_{s_{neg}} = \left[2(GW/S)/\rho C_{N_{neg}}\right]^{1/2}$

$V_{s_{neg}} = \left[2(50)/.0023772(1.1)\right]^{1/2}$

$V_{s_{neg}} = 196$ fps

$V_{s_{neg}} = 116$ knts



CALC	D. HENSLEY	11-02-86	REVISED	DATE	FIGURE A.1: V-n DIAGRAM 25 PAX
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					PAGE A.5

CALCULATE V_{S_1} :

$C_{L_{MAX}} = 1.4$

$C_{N_{MAX}} = (1.1)\ 1.4 = 1.54$

$V_{S_1} = \{ 2\ (GW/S)\ /\ \rho\ C_{N_{MAX}} \}^{1/2}$

$V_{S_1} = [2\ (31,395/449)/(0.0023769)(1.54)]^{1/2}$

$V_{S_1} = 195\ fps = 116\ kts$

CALCULATE V_A :

ASSUME: LIMIT LOAD FACTOR = 2.68

$W = (2.68)(31,395) = 84,139\ lbs$

$V_A = [2\ (84139/449)/(0.0023769)(1.54)]^{1/2}$

$V_A = 320\ fps = 189\ kts.$

CALCULATE V_C:

I - $V_C = (189 + 43)\ kts$

$V_C = 232\ kts$

II - AT MACH = 0.70 , h = 30,000 ft. : $\bar{q} = 215.6\ psf$

AT SEA-LEVEL : $V = 426\ fps$

$V_C = 252\ kts$

CALCULATE V_D:

$V_D = 1.25\ V_C$

$V_D = 1.25\ (252) = 315\ kts$

CALCULATE NEGATIVE STALL SPEED LINE:

ASSUME: $C_{L_{MAX_{NEG}}} = -1.0$

$C_{N_{MAX_{NEG}}} = 1.1\ C_{L_{MAX_{NEG}}} = -1.1$

$$V_{S_{NEG}} = \{ 2\,(GW/S) / \rho\, C_{N_{MAX_{NEG}}} \}^{1/2}$$

$$V_{S_{NEG}} = \{ 2\,(31,395/449) / (0.0023769)(1.1) \}^{1/2}$$

$$V_{S_{NEG}} = 231 \text{ fps} = 137 \text{ kts.}$$

CALCULATE DESIGN LIMIT LOAD FACTOR:

$$n_{Lim_{pos}} \geq 2.1 + \{ 24,000 / (W + 10,000) \}$$

$$n_{Lim_{pos}} \geq 2.1 + \{ 24,000 / (31,395 + 10,000) \} = 2.68$$

$$n_{Lim_{pos}} = 2.68$$

$n_{Lim_{neg.}} \geq -1.0$ UP TO V_C, VARIES LINEARLY FROM THE VALUE AT V_C TO ZERO AT V_D.

CALCULATE LOAD FACTOR LINES:

$$n_{lim} = 1 + (K_g U_{de} V C_{L_\alpha}) / 498\,(GW/S)$$

$$K_g = 0.88\,\mu_g / (5.3 + \mu_g)$$

$$\mu_g = 2\,(GW/S) / \rho\, \bar{c}\, g\, C_{L_\alpha}$$

$$\rho = 0.0023769 \text{ slugs/ft}^3$$

$$\bar{c} = 6.49 \text{ ft}$$

$C_{L_{\alpha_A}} = 5.11 \text{ rad}^{-1}$ WHERE FROM?

$$\mu_g = 2\,(31395/449) / (0.0023769)(6.49)(32.2)(5.11)$$

$$\mu_g = 55.09$$

$$K_g = 0.88\,\mu_g / (5.3 + \mu_g)$$
$$= 0.88(55.09)/(5.3 + 55.09)$$
$$K_g = 0.803$$

$$n_{lim} = 1 + (K_g U_{de} V C_{L_\alpha})/498\,(GW/S)$$
$$n_{lim} = 1 + \left[(0.803)\,U_{de} V\,(5.11)\,/\,498\,(31{,}395/449)\right]$$
$$\underline{n_{lim} = 1 + \left[1.178 \times 10^{-4}\,U_{de} V\right]}$$

FOR V_B GUST LINE:

SL TO 20,000 ft: $U_{de} = 66$ fps

20,000 TO 30,000 ft.: $U_{de} = 47.33 - 0.000933\,h$
$= 47.33 - 0.000933\,(30{,}000\text{ ft})$
$U_{de} = 19.34$

USE: $U_{de} = 66$ fps

$$\underline{n_{lim} = 1 + 7.775 \times 10^{-3}\,V}$$

FOR V_c GUST LINE:

SL TO 20,000 ft: $U_{de} = 50$ fps

20,000 TO 30,000 ft: $U_{de} = 66.67 - 0.000833\,h$
$= 66.67 - 0.000833\,(30{,}000)$
$U_{de} = 41.68$ fps

USE: $U_{de} = 50$ fps

$$\underline{n_{lim} = 1 + 5.890 \times 10^{-3}\,V}$$

FOR V_D GUST LINE:

SL TO 20,000 ft : $U_{de} = 25$ fps

20,000 TO 30,000 ft: $U_{de} = 16.67 - 0.000417h$

$= 16.67 - 0.000417\,(30,000\text{ ft})$

$U_{de} = 4.16$

USE: $U_{de} = 25$ fps

$$n_{lim} = 1 + 2.945 \times 10^{-3}\,V$$

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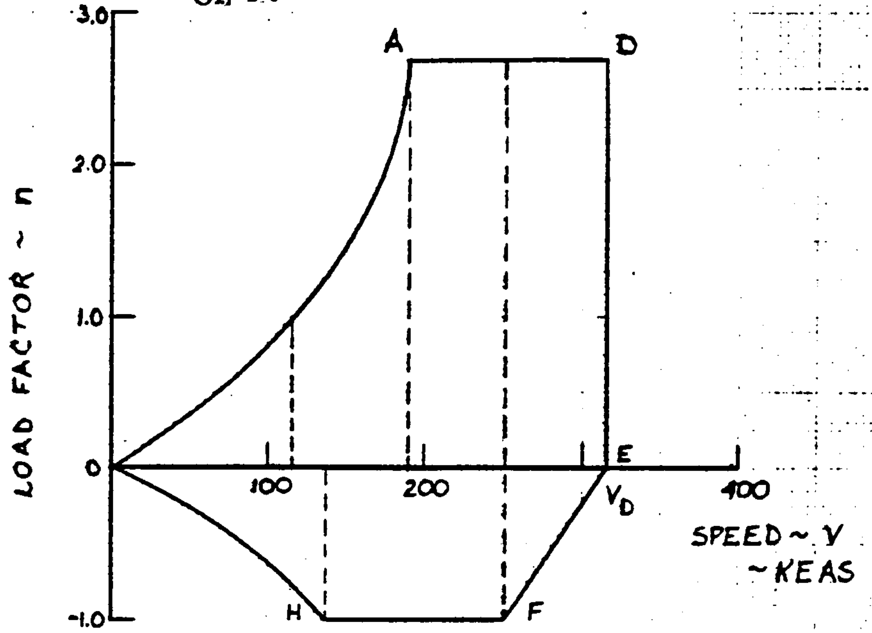
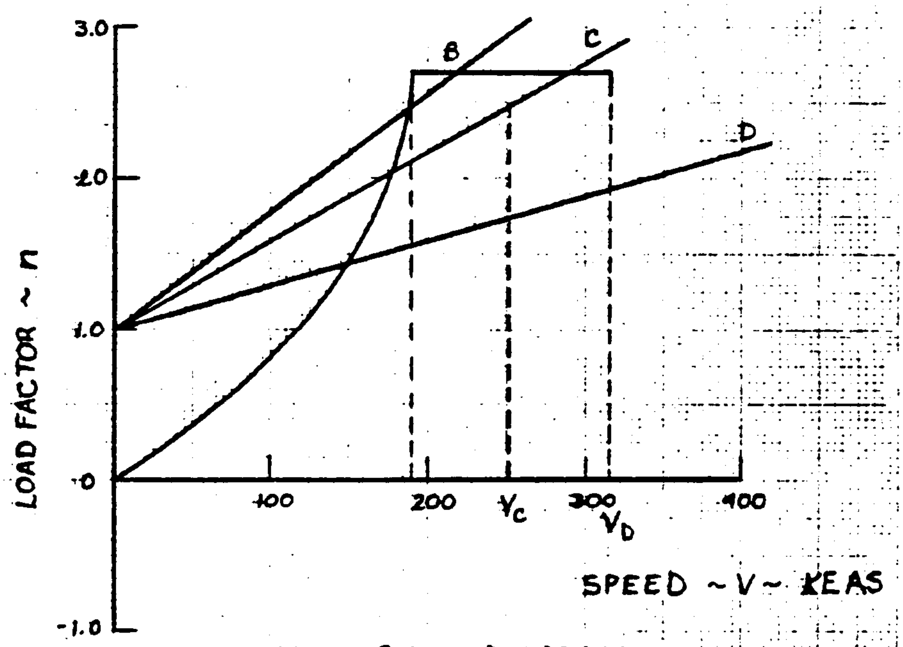


V-n MANEUVER DIAGRAM



V-n GUST DIAGRAM

CALC	10-22-86	JKM	REVISED	DATE	V-n DIAGRAMS FOR 36-PASS. REGIONAL TRANSPORT	FIG A.2
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Step 1 - Determination of V_{S_1}

$C_{L_{max}} = 1.5$ GW = W_{TO} $S = 592\ ft^2$

From Eqn. (4.6) $C_{N_{max}} = 1.1 \times 1.5 = 1.65$

$(GW/S) = 71.0$ psf

From Eqn. (4.19),

$$V_{S_1} = \left[2(71)/(.002377)(1.65)\right]^{1/2}$$

$$= \quad V_{S_1} = 190.3\ \text{fps} = 113\ \text{kts} \longleftarrow$$

Step 2 - Determination of V_A:

From Eqn. (4.23),

$$n_{lim_{pos}} \geq 2.1 + (24000/(W+10000))$$

$$n_{lim_{pos}} \geq 2.1 + (24000/(42057+10000))$$

or $n_{lim_{pos}} \geq 2.56$; will use 2.50

Thus, from Eqn. (4.22),

$$V_A \geq V_{S_1} n_{lim}^{1/2} = (190.3)(2.50)^{1/2} = 301\ \text{fps}$$

Thus $V_A \geq 178$ kts $\longleftarrow$

Step 3 Constructing the gust load factor lines

$\bar{c} = 7.46$ ft $C_{L_\alpha} = 5.12\ rad^{-1}$

From Eqn. (4.18),

$$\mu_g = 2(GW/S)/\rho \bar{c} g C_{L_\alpha}$$

$$= 2(71.0)/(.002377)(7.46)(32.2)(5.12)$$

$$= \quad \mu_g = 48.6$$

From Eqn. (4.17),

$$K_g = 0.88\mu_g/(5.3+\mu_g)$$

$$= .88(48.6)/(5.3+48.6)$$

$$= \quad K_g = 0.794$$

From Eqn. (4.16),

$$n_{lim} = 1 + (K_g U_{de} V C_{L\alpha}) / 498 (GW/S)$$

$$= 1 + (.794 \times U_{de} V (5.12)) / 498 (71)$$

$$= n_{lim} = 1 + 1.149 \times 10^{-4} U_{de} V$$

V_B Line

From sealevel to 20,000 ft : $U_{de} = 66$ fps

At 30,000 ft : $U_{de} = 47.33 - (.000933)(30,000)$

$U_{de} = 19.34$

– use $U_{de} = 66$ fps

$\therefore \quad n_{lim} = 1 + .00758 V$ ←

V_C Line

Sealevel to 20,000 ft : $U_{de} = 50$ fps

At 30,000 ft : $U_{de} = 66.67 - (.000833)(30,000)$

$U_{de} = 41.68$

– use $U_{de} = 50$ fps

$\therefore \quad n_{lim} = 1 + .00575 V$ ←

V_D Line

Sealevel to 20,000 ft : $U_{de} = 25$ fps

At 30000 ft : $U_{de} = 16.67 - (.000417)(30000)$

$U_{de} = 4.16$ fps

– use $U_{de} = 25$ fps

$\therefore \quad n_{lim} = 1 + .00287 V$ ←

Step 4 Determination of V_B

V_B is determined from the intersection of the $C_{N_{max}}$ line and the V_B gustline. From Fig. ___ this is determined to be:

$$V_B = 172 \text{ kts}$$

Step 5 Determination of V_C

From Eqn. (4.20) $V_C = V_B + 43$ kts

$\therefore$ $V_c = 172 + 43 = 215$ kts

However, the mission specification calls for a cruise speed of M= 0.70 at 30,000 ft. This corresponds to 412 kts at 30,000 ft or a $\bar{q} = 216$ psf. At sealevel the corresponding KEAS is 252 kts. Since this is larger than 215 kts,

$$V_c = 252 \text{ kts}$$

Step 6 Determination of V_D

From Eqn. (4.21), $V_D = 1.25\, V_c = 1.25(252)$

Thus, $V_D = 315$ kts

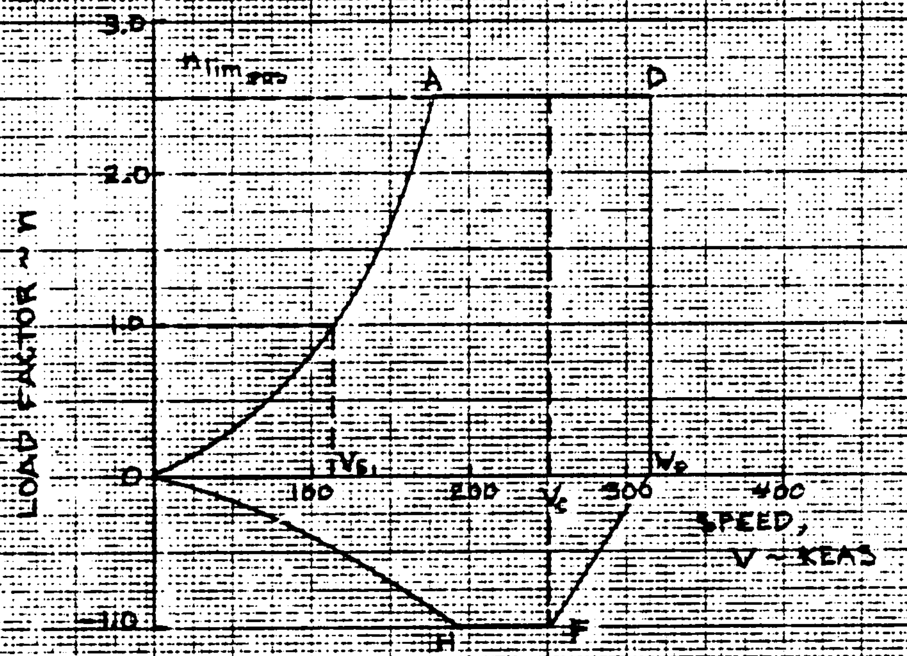
Step 7 Determination of the Negative Stall Line

Assume $C_{L_{max_{neg}}} = -1.0$ thus $C_{N_{max_{neg}}} = -1.1$

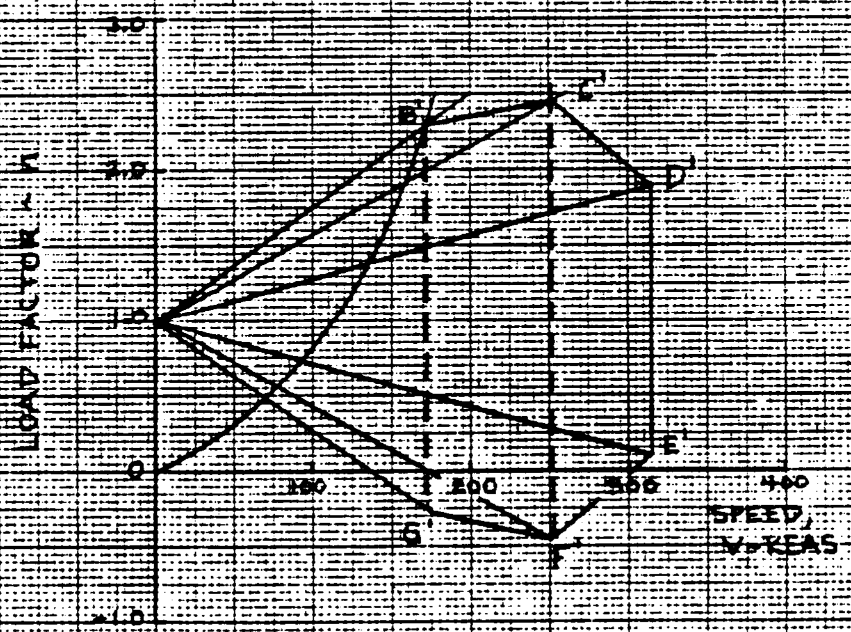
From Eqn. (4.4), $V_{s_{neg}} = 2\left[(GW/S)/\rho\, C_{N_{max}}\right]^{1/2}$

$$V_{s_{neg}} = 2\left[(71.0)/(.002377)(1.1)\right]^{1/2}$$

$$= V_{s_{neg}} = 330 \text{ fps} = 195 \text{ kts}$$



V-n Maneuver Diagram



V-n Gust Diagram

CALC	M. RUSSELL	10-23	REVISED	DATE	50 PASSENGER V-n DIAGRAMS	AE 790
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DETERMINE V_{S_1} :

$C_{L_{max}} = 1.5$

$C_{N_{max}} = (1.1)(1.5) = 1.65$

$V_{S_1} = \{2\,(GW/S)\,/\,\rho\, C_{N_{max}}\}^{1/2}$

$V_{S_1} = [2\,(60683/722)\,/\,(.0023769)(1.65)]^{1/2}$

$V_{S_1} = 207$ fps $= 123$ kts

DETERMINE V_A : ASSUME A LIMIT LOAD FACTOR OF 2.5 -

$W = (2.5)(60683) = 151708$ lbs

$V_A = [2\,(151708/722)\,/\,(.0023769)(1.65)]^{1/2}$

$V_A = 327$ fps $= 194$ kts ←

DETERMINE V_C :

I - $V_C = 194 + 43$

$V_C = 237$

II - AT MACH .70 , 30,000 ft $\bar{q} = 215.6$ psf

AT SEALEVEL : $V = 426$ fps

$V = 252$ kts ←

DETERMINE V_D :

$V_D = 1.25\, V_C$

$V_D = (1.25)(252) = 315$ kts ←

DETERMINE NEGATIVE STALL SPEED LINE -

ASSUME: $C_{L_{MAX_{NEG}}} = -1.0$

$C_{N_{MAX_{NEG}}} = (1.1)(-1.0) = -1.1$

$V_{S_{NEG}} = \{ 2 (GW/S) / \rho \; C_{N_{MAX_{NEG}}} \}^{1/2}$

$V_{S_{NEG}} = \{ 2 (60683/722) / (.0023769)(1.1) \}^{1/2}$

$V_{S_{NEG}} = 254 \text{ fps} = 150 \text{ kts}$

DETERMINE DESIGN LIMIT LOAD FACTOR -

$n_{lim_{pos}} \geq 2.1 + \{ 24,000 / (W + 10,000) \}$

$n_{lim_{pos}} \geq 2.1 + \{ 24,000 / (60683 + 10,000) \} = 2.44$

$n_{lim_{pos}}$ ALWAYS ≥ 2.5 $\therefore$ $n_{lim_{pos}} = 2.5$

$n_{lim_{neg}} = -1.0$ UP TO V_C, VARIES LINEARLY TO ZERO FROM V_C TO V_D

DETERMINE LOAD FACTOR LINES -

$n_{lim} = 1 + (K_g \, U_{de} \, V \, C_{L_\alpha}) / 498 \, (GW/S)$

$K_g = .88 \mu_g / (5.3 + \mu_g)$

$\mu_g = 2 (GW/S) / \rho \bar{c} \, g \, C_{L_\alpha}$

$\rho = .0023769 \; s^2/ft^3$
$\bar{c} = 90'' = 7.5'$
$C_{L_{\alpha_A}} = 5.8 \text{ rad}^{-1}$

$\mu_g = 2 (60683/722) / (.0023769)(7.5)(32.17)(5.8)$

$\mu_g = 50.54$

$K_g = (.88)(50.54) / (5.3 + 50.54)$

$K_g = .796$

$n_{lim} = 1 + \{(.746)\, U_{de}\, V\, (5.8)\} / 498\, (60682/722)$

$n_{lim} = 1 + (1.034 \times 10^{-4})\, U_{de}\, V$

DETERMINE V_B: $U_{de} = 47.33 - (.000933)(30{,}000)$

$U_{de} = 19.34$ - USE 66 fps

$n_{lim} = 1 + .00682\, V$ ←

DETERMINE V_C: $U_{de} = 66.67 - (.000833)(30{,}000)$

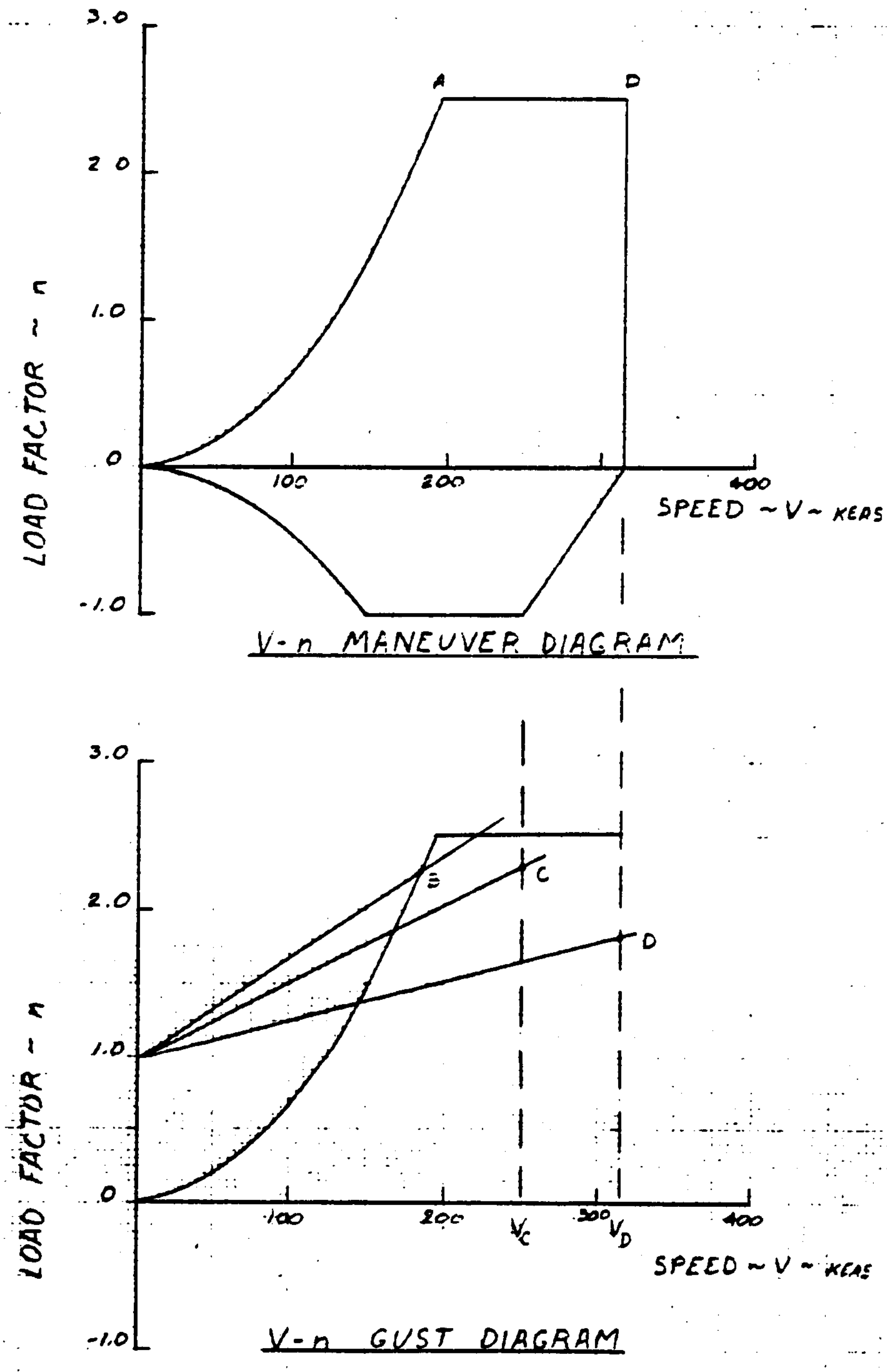
$U_{de} = 41.68$ - USE 50 fps

$n_{lim} = 1 + .00517\, V$ ←

DETERMINE V_D: $U_{de} = 16.67 - (.000417)(30{,}000)$

$U_{de} = 4.16$ - USE 25 fps

$n_{lim} = 1 + .00259\, V$ ←



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CALC					V-n DIAGRAMS FOR THE 75 PAX TRANSPORT	A.4
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Step 1. Determination of +1g stall speed, V_{s_1}

$$V_{s_1} = \{ 2\,(GW/S)/\rho\, C_{N_{max}} \}^{1/2} \qquad (1)$$

where,

$GW = 80{,}716$ lbs
$S = 923\ ft^2$
$\rho = 0.002377\ slugs/ft^3$

$C_{N_{max}} = 1.1\, C_{L_{max}} = 1.65$

thus,

$$V_{s_1} = \{ 2\,(80716/923)/(0.002377 \cdot 1.65) \}^{1/2}$$

$$V_{s_1} = 211\ fps = 125\ knots$$

Step 2. Determination of design limit load factor, n_{lim}

The positive limit maneuvering load factor, $n_{lim_{pos}}$ is determined from:

$$n_{lim_{pos}} \geq 2.1 + \{ 24000/(W + 10{,}000) \} \qquad (2)$$

thus,

$$n_{lim_{pos}} \geq 2.1 + \{ 24000/(80716 + 10{,}000) \}$$

$$n_{lim_{pos}} \geq 2.36$$

but the exception is

$n_{lim_{pos}} \geq 2.5$ at <u>all</u> times

Step 3. Determination of design maneuvering speed, V_A

$$V_A \geq V_{s_1}\, n_{lim}^{1/2} \qquad (3)$$

$$V_A \geq 198\ knots$$

Step 4. Construction of gust load factor lines.

The gust load factor lines are defined by the following equation:

$$n_{lim} = 1 + (K_g U_{de} V C_{L_\alpha})/498\,(GW/S) \qquad (4)$$

where

$$\mu_g = 2(GW/S)/\rho \bar{c} g C_{L_\alpha} \;;\; C_{L_\alpha} = 6.07 \text{ rad}^{-1} \qquad (5)$$

$$\mu_g = 2(85716/923)/(0.002377)(8.33)(32.2)(6.07)$$

$\mu_g = 45.2$ at S.L.

$\mu_g = 120.8$ at 30,000 ft.

and

$$K_g = 0.88\mu_g/(5.3+\mu_g) \qquad (6)$$

$K_g = 0.788$ at S.L.

$K_g = 0.843$ at 30,000 ft.

thus,

$n_{lim} = 1 + U_{de} V \cdot 1.098 \times 10^{-4}$ at S.L.

For the V_B gust line:

$U_{de} = 66$ fps

$n_{lim} = 1 + V \cdot 7.25 \times 10^{-3}$

For the V_C gust line:

$U_{de} = 50$ fps

$n_{lim} = 1 + V \cdot 5.49 \times 10^{-3}$

For the V_D gust line:

$U_{de} = 25$ fps

$n_{lim} = 1 + V \cdot 2.75 \times 10^{-3}$

Step 5. Construct the $C_{N_{max}}$ line and gust lines.

From the V-n gust and maneuver diagrams,

$V_B = 195$ knots

V_E follows from the intersect of the +1g stall line and the V_E gust line.

Step 6. Determination of design cruising speed, V_C

$V_C \geq V_E + 43$ knots (7)

thus,

$V_C \geq 195 + 43 = 238$ knots

From the mission requirements,

$M_{cr} = 0.70$ at 30,000 ft.

$\bar{q}_{cr} = \frac{1}{2}(0.0008593)(994.7 \cdot 0.70)^2 = 215.6$ psf

At sea level this corresponds to

$V_{cr} = 426$ fps $= 252$ knots

which is > 238 knots required for gust requirements.

Step 7. Determination of design diving speed, V_D

$V_D \geq 1.25\ V_C$ (8)

thus,

$V_D \geq 315$ knots

Step 8. Determination of negative stall speed line.

It will be assumed that $C_{L_{max\,neg}} = -1.0$ and

$C_{N_{max\,neg}} = -1.1$

thus,

$V_{S_{neg}} = \{ 2(80,716/923)/(0.002377)(1.10)\}^{1/2}$

$V_{S_{neg}} = 259$ knots

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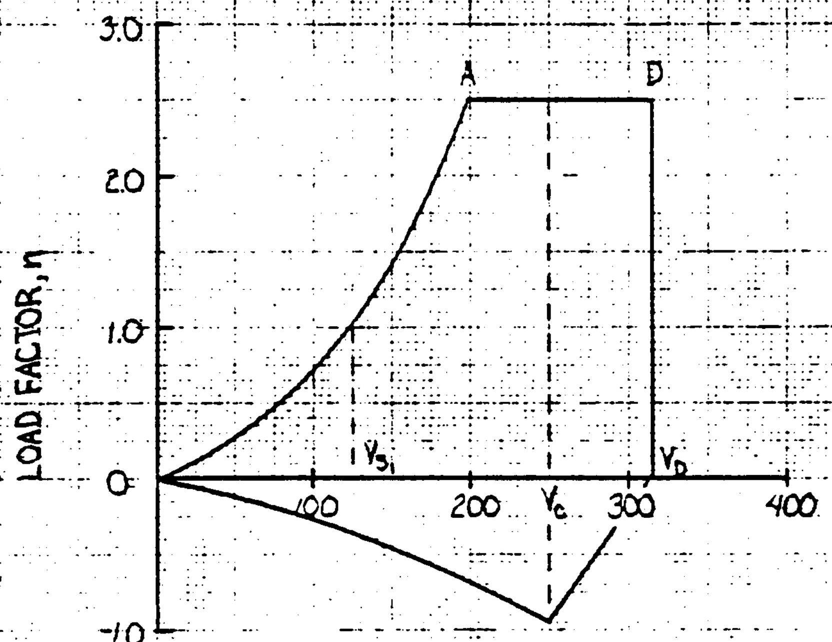
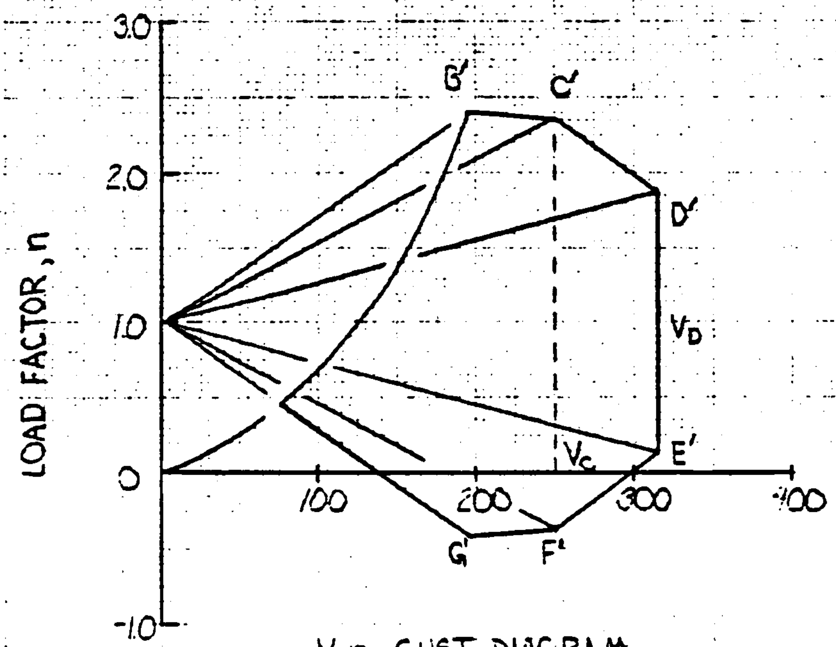


V-n MANEUVER DIAGRAM



V-n GUST DIAGRAM

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FIGURE A.5. 100 PASSENGER TWIN BODY V-n DIAGRAMS.

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APPENDIX B
FUSELAGE STRINGER AND BULKHEAD DESIGN

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B.5	BULKHEAD ΔW STUDY	B.12

B.1 INTRODUCTION

THE PURPOSE OF THIS APPENDIX IS TO DETERMINE DIMENSIONS AND WEIGHTS OF FUSELAGE STRUCTURAL COMPONENTS:

1) STRINGERS
2) BULKHEADS

THE FUSELAGE STRUCTURAL COMPONENTS WILL BE MADE OF ARAMIDE - ALUMINUM (ARALL). THE WEIGHTS SAVINGS ARALL AFFORDS IS TABULATED IN THE COMPONENT DESIGN SECTIONS.

B.2 CALCULATE CROSS SECTIONAL AREA OF STRINGERS

FOR THE EXTERNAL BENDING MOMENT, THE BENDING STRESS CAN BE CALCULATED BY THE FOLLOWING EQUATION:

$$\sigma_b = \frac{Mc}{I}$$

WHERE:

M - IS THE MAXIMUM (CRITICAL) BENDING MOMENT (THIS WAS CALCULATED IN SECTION)

C - THE EXTREME FIBER

I - MOMENT OF INERTIA

FOR 2024 ALUMINUM

$$\sigma_b = 32{,}000 \text{ PSI}$$

AND

FROM SECTION . , THE (APPROX.) MAXIMUM BENDING MOMENT WAS CALCULATED TO BE:

FOR THE 50 PASSENGER

$m = 149,960$ in·lbs

FOR THE 36 PASSENGER

$m = 113,270$ in·lbs

FOR THE 25 PASSENGER

$m = 74,280$ in·lbs

SO SOLVING FOR THE VALUE (c/I)

50 PASSENGER $c/I = 0.2134\ in^{-3}$
36 PASSENGER $c/I = 0.2825\ in^{-3}$
25 PASSENGER $c/I = 0.4308\ in^{-3}$

NOTE: THE VALUES (c/I) ARE FOR THE GIVEN SECTION AND NOT FOR A SINGLE STRINGER.

SINCE THE DIAMETER OF THE FUSELAGE IS THE SAME FOR OF THE THREE AIRCRAFT, THE VALUE OF c IS:

DIAMETER = 96.6"

& $c = \frac{D}{2} = 48.3''$

SOLVING FOR THE MOMENT OF INERTIA

FOR 50 PASSENGER: $I = 226.3 \text{ in}^4$

FOR 36 PASSENGER: $I = 171.0 \text{ in}^4$

FOR 25 PASSENGER: $I = 112.1 \text{ in}^4$

TREATING EACH STRINGER AS A POINT MASS RATHER THAN A Z-STRINGER, THE MOMENT OF INERTIA FOR THE SECTION CAN BE CALCULATED BY USING THE FOLLOWING EQUATION:

FOR A GIVEN SECTION:

$$I = \Sigma A y^2$$

WHERE

A - IS THE SECTIONAL AREA OF THE STRINGER (TOTAL STRINGER AREA)

Y - IS THE VERTICAL DISTANCE FROM THE CENTER LINE AXIS

FROM THE ABOVE EQUATION, THERE IS TWO UNKNOWNS THE TOTAL AREA AND THE VERTICAL DISPLACEMENT OF THE STRINGERS. SO TO SOLVE FOR THE TOTAL AREA, THE VERTICAL DISPLACEMENT BETWEEN STRINGERS WAS ASSUMED TO BE 10". THIS DISPLACEMENT VALUE WAS OBTAINED FROM REFERENCE 1.

BY

SINCE ALL THREE FUSELAGES (25, 36 & 50 PASSENGERS) HAVE THE SAME DIAMETER OF 96.6" OR 8.05'. FROM SIMPLE GEOMETRY (FOR HALF - πr), IT WAS DETERMINED THAT 28 STRINGER WOULD BE REQUIRED. ALSO, KNOWING THE TOTAL HEIGTH OF FUSELAGE AND THE NUMBER OF STRINGERS, THAT ARE EVENLY PLACED, THE VERTICAL DISTANCE FOR EACH STRINGER CAN BE DETERMINED.

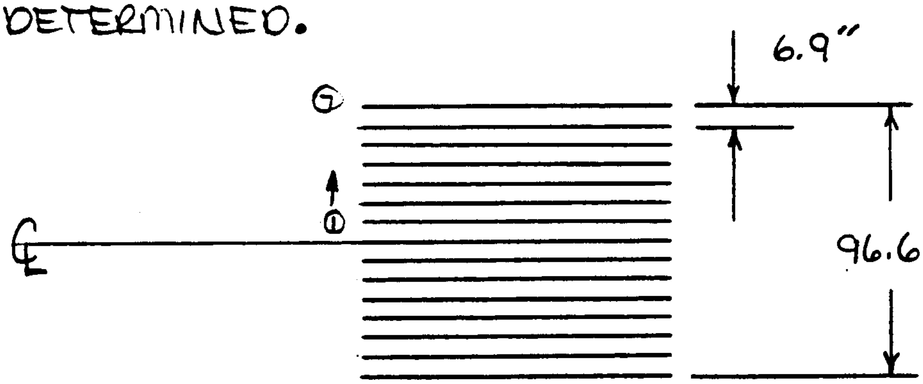

FIGURE 1 STRINGER SPACING

DISPLACEMENT	STRINGERS
$Y_1 = 6.9''$	2
$Y_2 = 13.8''$	2
$Y_3 = 20.7''$	2
$Y_4 = 27.6''$	2
$Y_5 = 34.5''$	2
$Y_6 = 41.4''$	2
$Y_7 = 48.3''$	1
	13 TOTAL FOR HALF

NOTE: THIS IS FOR HALF OF THE FUSELAGE.

DS

SO

$$I = A \sum y^2$$

$$= 2A(2y_1^2 + 2y_2^2 + 2y_3^2 + 2y_4^2 + 2y_5^2 + 2y_6^2 + y_7^2 + 2y_0^2)$$

where $y_0 = 0$

AFTER SUBSTITUTION:

$$I = 2A\,(6665.4)$$

FOR 50 PASSENGER:

$$A = 0.17 \text{ in}^2$$

FOR 36 PASSENGER:

$$A = 0.13 \text{ in}^2$$

FOR 25 PASSENGER:

$$A = 0.08 \text{ in}^2$$

FOR Z STRINGERS THESE VALUES SEEM REASONABLE

HOWEVER, THE 25 PASSENGER SEEMS SMALL.

TO WORK COMMONALITY INTO THE DESIGN OF THE STRINGERS, IT MIGHT BE POSSIBLE TO SPACE THE STRINGERS SUCH THAT THE AREAS ARE EQUAL.

STRINGER WEIGHT CALCULATIONS

ALUMINUM DENSITY 174.8 lb/ft³

ARALL DENSITY 153.0 lb/ft³

MATERIAL	50 PAX	36 PAX	25 PAX
ALUMINUM	20.4	12.3	7.1
ARALL	17.9	10.8	6.2
Δ WEIGHT	2.5	1.5	0.9

WHERE THE VOLUME OF ONE STRINGER

FOR 50 PASSENGER

$$V = (0.17/144)(94.6) = 0.1169\ ft^3$$

FOR 36 PASSENGER

$$V = (0.13/144)(78.1) = 0.07054\ ft^3$$

FOR 25 PASSENGER

$$V = (0.084/144)(69.4) = 0.04048\ ft^3$$

NOTE: THESE VALUES SEEM TO MAKE A SMALL CONTRIBUTION TO THE OVERALL FUSELAGE WEIGHT

(*) POSSIBLE ERROR – (S/I) VALUES

BENDING MOMENTS

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B.3 TAIL LOADS

$$C_{m_{\alpha_{a-t}}} = (X_{cg_{AFT}} - X_{AC_{WB}})(C_{L_{\alpha_{WB}}})\alpha$$

50 PAX Assumed $\alpha_{cruise} = -2^\circ$

$$C_{m_{a-t}} = (0.325 - (-0.058))(4.72)(-0.0349)$$

$$= -0.06309$$

36 PAX

$$C_{m_{a-t}} = (0.33 - (-0.08))(4.71)(-0.0349)$$

$$= -0.06741$$

25 PAX

$$C_{m_{a-t}} = (0.32 - (-0.09))(4.71)(-0.0349)$$

$$= -0.06741$$

CONTINUE

$$C_t = \frac{\bar{c}}{L_t} C_{m_{a-t}}$$

50 PAX

$$C_t = \frac{7.46}{41.1}(-0.06309)$$

$$= -0.01145$$

36 PAX

$$C_t = \frac{6.5}{39}(-0.06741)$$

$$= 0.01124$$

25 PAX

$$C_t = \frac{6.28}{38}(-0.06741)$$

$$= 0.01114$$

CONTINUE

$$\text{TAIL LOAD} = C_t \, \bar{q} \, S$$

Where $\bar{q}$ WAS DETERMINED AT 30,000 ft

$\rho = 0.0008893$ slugs/ft^3 $a = 994.7$ ft/sec

FOR 50 PAX

$$L_t = -0.01145\,(215.6)\,(592)$$

$$= -1461.2 \text{ lbs}$$

FOR 36 PAX

$$L_t = -0.01124\,(215.6)\,(449)$$

$$= -1088.0 \text{ lbs}$$

FOR 25 PAX

$$L_t = -0.01114\,(215.6)\,(421)$$

$$= -1011.0 \text{ lbs}$$

* WHERE L_t - TAIL LOAD.

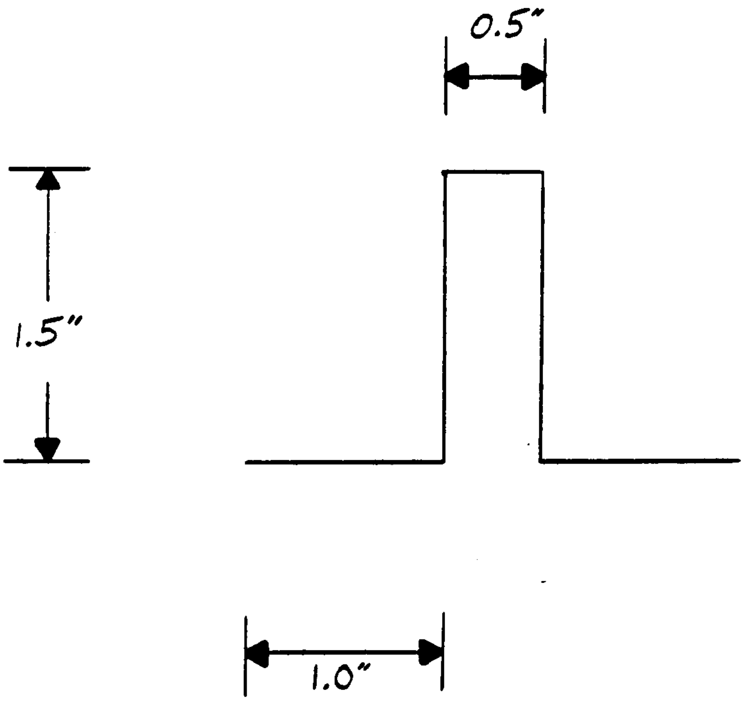
B.4 50 PAX BULKHEAD DESIGN

FROM THE METHODS DESCRIBED IN AIRPLANE DESIGN PART III, BULKHEAD SPACING FOR THE 50 PASSENGER AIRPLANE WAS DETERMINED TO BE 20 INCHES.

USING THE 20 INCH SPACING OF THE BULKHEADS, THE 50 PASSENGER AIRPLANE WAS DETERMINED TO CONTAIN 53 BULKHEADS AS SHOWN IN THE STRUCTURAL ARRANGEMENTS IN CH. 2.

B.5 BULKHEAD ΔW STUDY

THE FOLLOWING FIGURE IS A CROSS-SECTION VIEW OF THE PROPOSED BULKHEAD:



THE BULKHEAD WEIGHT WILL BE EVALUATED USING SHEET THICKNESSES OF 0.06 INCH AND 0.10 INCH.

FUSELAGE DIAMETER = 96"
FUSELAGE PERIMETER = $2\pi r$ = 301.6"

THE BULKHEAD VOLUMES ARE AS FOLLOWS:

- FOR THE 0.06 INCH THICKNESS:
  $V = (301.6)(0.06)(5.5)$
  $V = 99.5\ in^3 = 0.058\ ft^3$

- FOR THE 0.10 INCH THICKNESS:
  $V = (301.6)(0.10)(5.5)$
  $V = 165.9\ in^3 = 0.096\ ft^3$

ALUMINUM DENSITY = 174.8 lb/ft^3
ARALL DENSITY = 153.0 lb/ft^3

	WEIGHT (LBS) .06" THICK	WEIGHT (LBS) .10" THICK	THICKNESS ΔW (LBS)
ALUMINUM	10.1	16.8	6.7
ARALL	8.9	14.7	5.8
MATERIAL ΔW (LBS)	1.2	2.1	

APPENDIX C WING SPAR AND WEB SIZING

The purpose of this appendix is to present the methods and calculations used to determine the required size of the wing spars and webs.

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C.1 INTRODUCTION

The purpose of this section is to determine the critical loads which the wing will encounter in flight, then to determine the wing structure necessary to carry the resulting forces and moments.

C.2 DETERMINATION OF CRITICAL LOADS

The method used to determined the spanwise aerodynamic load on the wing follows that of Reference 7. Tables C.1 through C.9 present the data used in determining the wing loadings for take-off, design dive, and landing velocities. From these, the span loadings are plotted in Figures C.1 through C.6.

C.3 SHEAR AND MOMENT DIAGRAMS

Using the critical loading condition, at design dive speed, the shear and moment at each wing section is determined using a method from Bruhn (Analysis & Design of Flight Vehicle Structures). This method is outlined in Table C.10. In addition to the shear and bending moment at each section, the required moment of inertia is determined as well.

C.4 SPAR AND WEB AREAS AND WEIGHTS

From the required moment of inertia, it is possible to determine the spar area needed. Although the advertised yield stress of Arall is 77,000 psi, it has been advised that a more realistic value of 55,000 psi be used. This is shown in Table C.11. A linear relationship is assumed between the spar cap area and the moment of inertia of the spar cap about its own centroidal axis. This amount is normally negligible but is included in the equation in Table C.11 anyway. The spar areas shown in Tables C.11 through C.14 are for one spar cap only.

The spar weight is calculated by multiplying the spar area times the section width times the material density, which is 174.8 lbs/ft^3 for aramid aluminum. The shear flow, web thickness, web area, and web weight are also determined, using the method shown in Table C.11. The total web plus spar weight for each airplane is determined as well. All numerical values for the methods shown in Tables C.10 and C.11 are presented in Tables C.12, C.13 and C.14.

C.5 RESULTS AND CONCLUSIONS

From the results of Tables C.12, C.13, and C.14, the required spar areas at the root are:

25 pax - 4.21 in^2

36 pax - 7.26 in^2

50 pax - 10.8 in^2

This is where a design choice has to be made. It appears that the best solution for commonality and weight purposes would be to arrange the torque boxes as shown in Figures C.15, C.16, and C.17. These torque boxes are arranged so that only one spar cap/stringer size (a standard 4 x 3.5 x 5/8 inch angle) is needed for all the airplanes. On the 25 passenger only four spar caps are needed as shown in Figure C.15. On the 36 passenger 7 of these are needed. One possible way to arrange them is as shown in Figure C.16. On the 50 passenger, 10 are needed; thus the arrangement shown in Figure C.17.

If no stringers were used, a highly concentrated load would be placed on the spar caps. Thus it appears more feasible to distribute the load on the 36 and 50 passenger airplanes as shown. There is no weight penalty involved when done this way.

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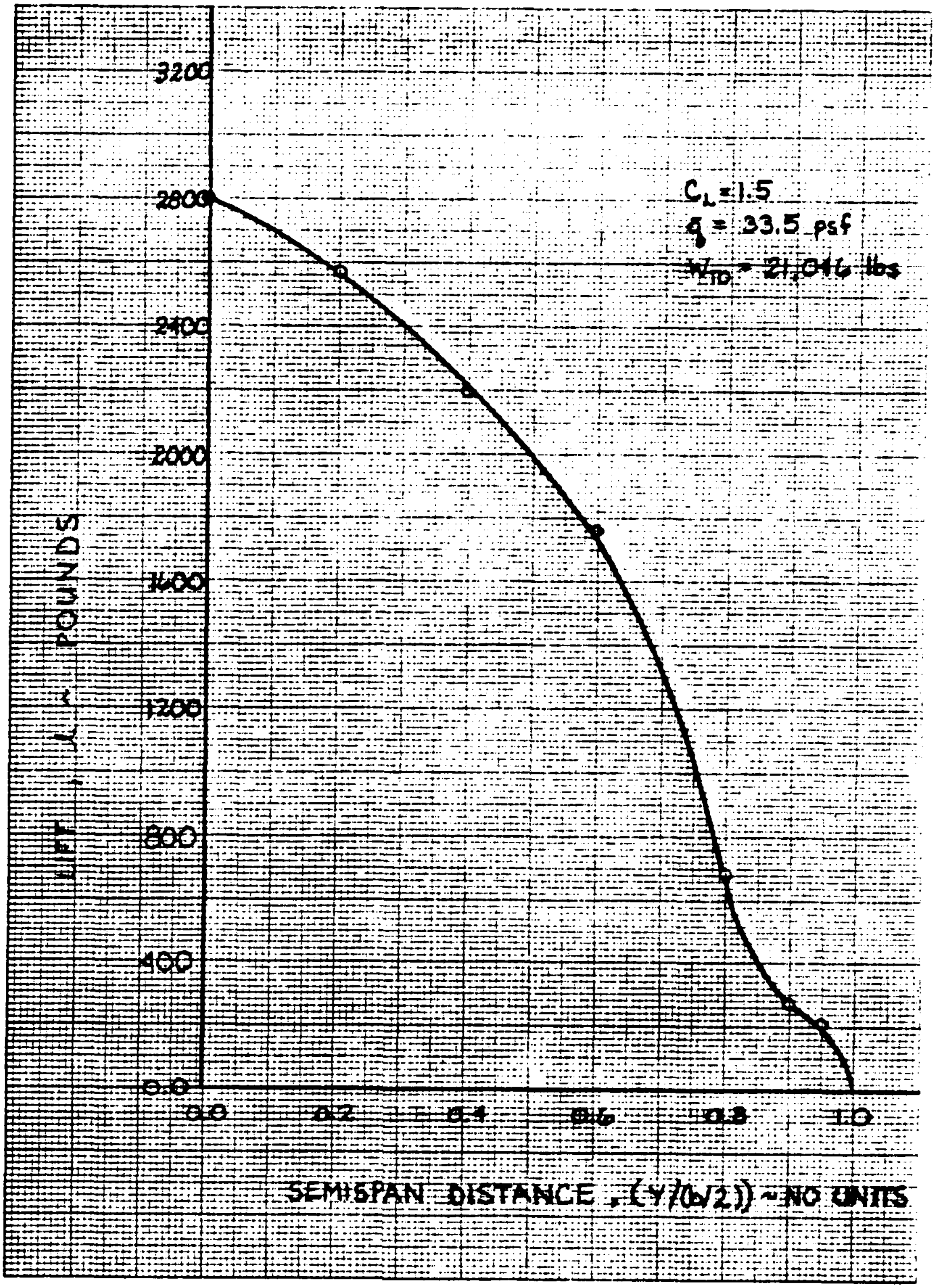

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Figure C.1 Load Diagram for 25 Pax Commuter at C_L = 1.5

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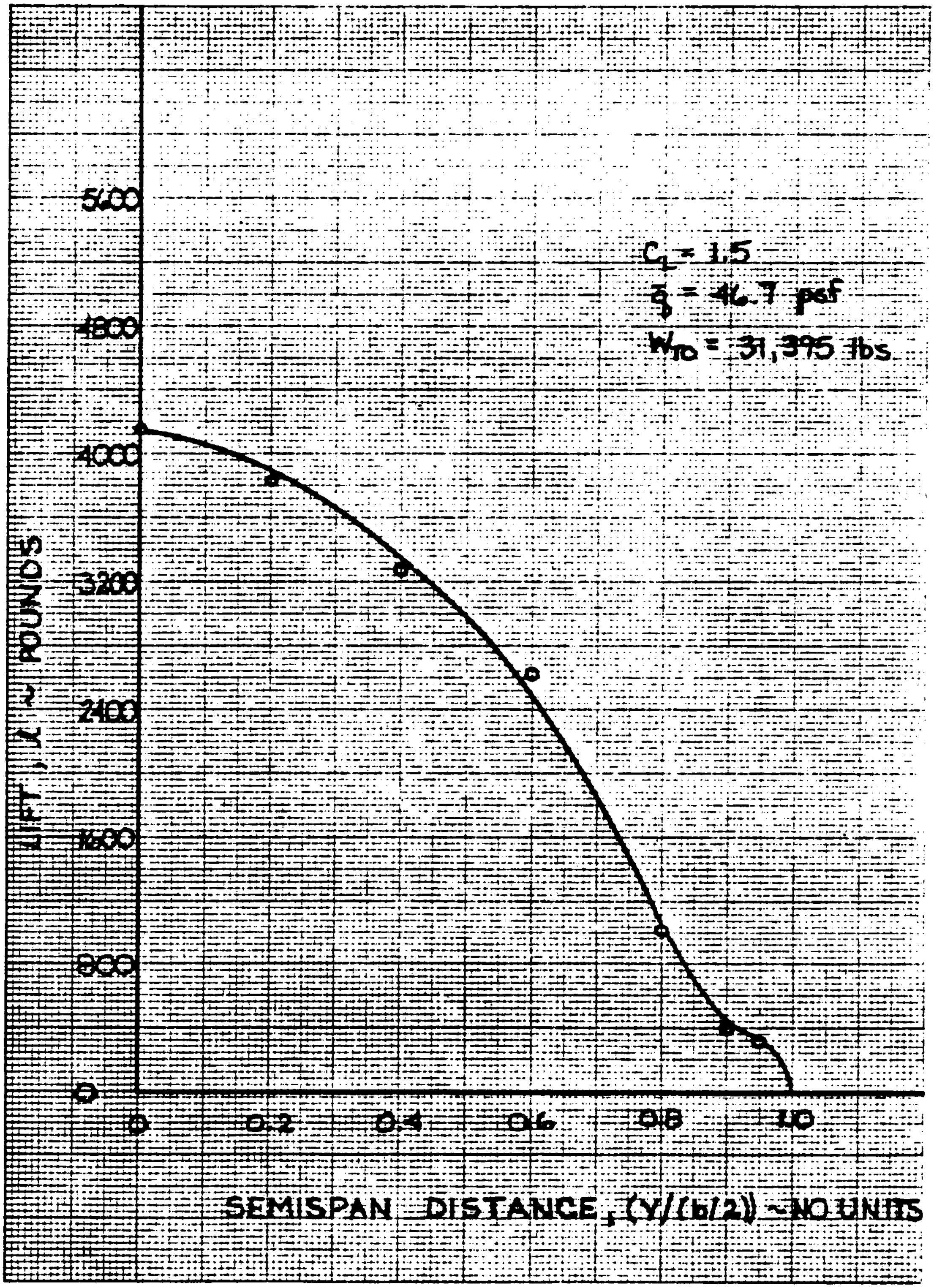

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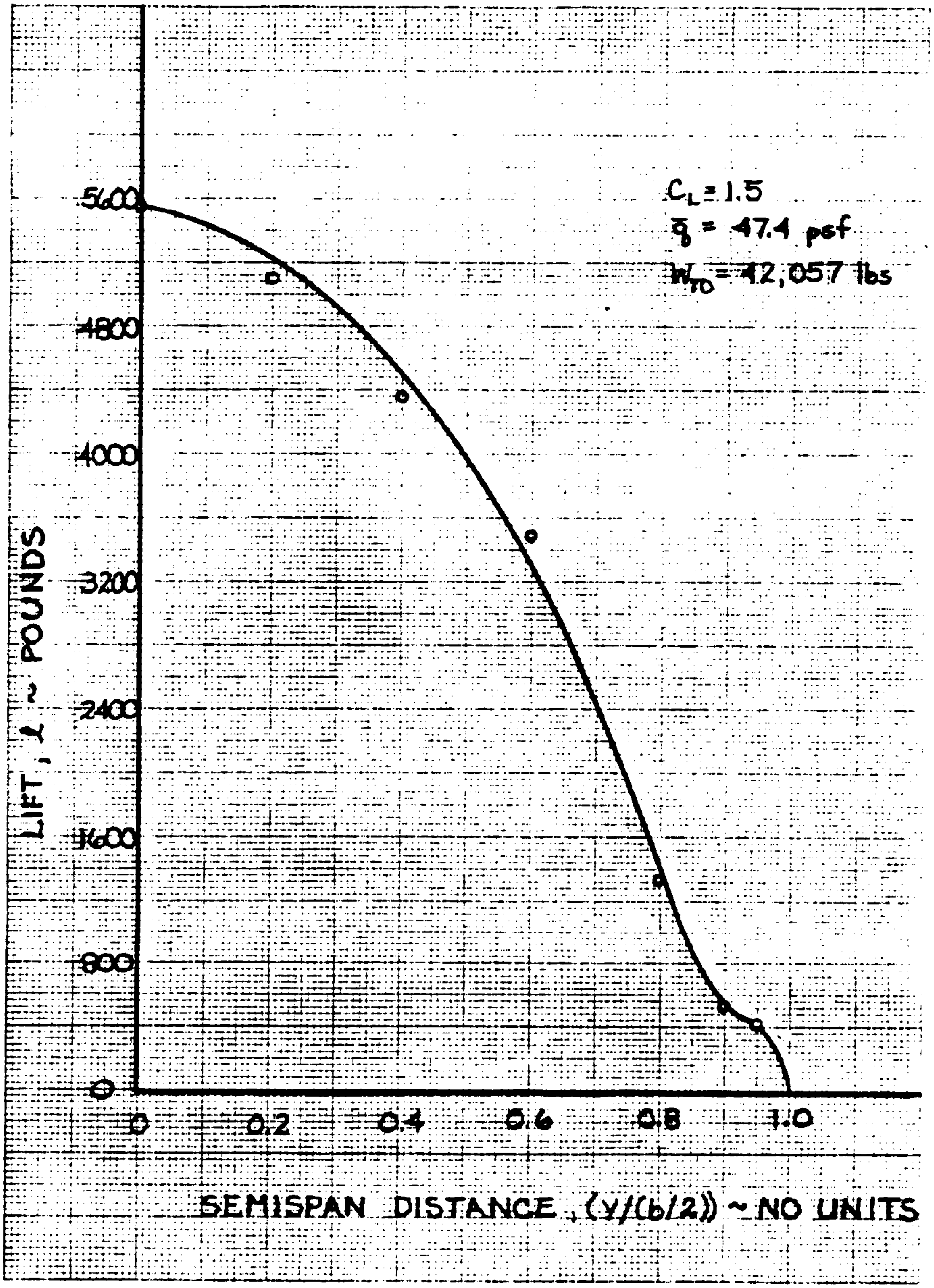

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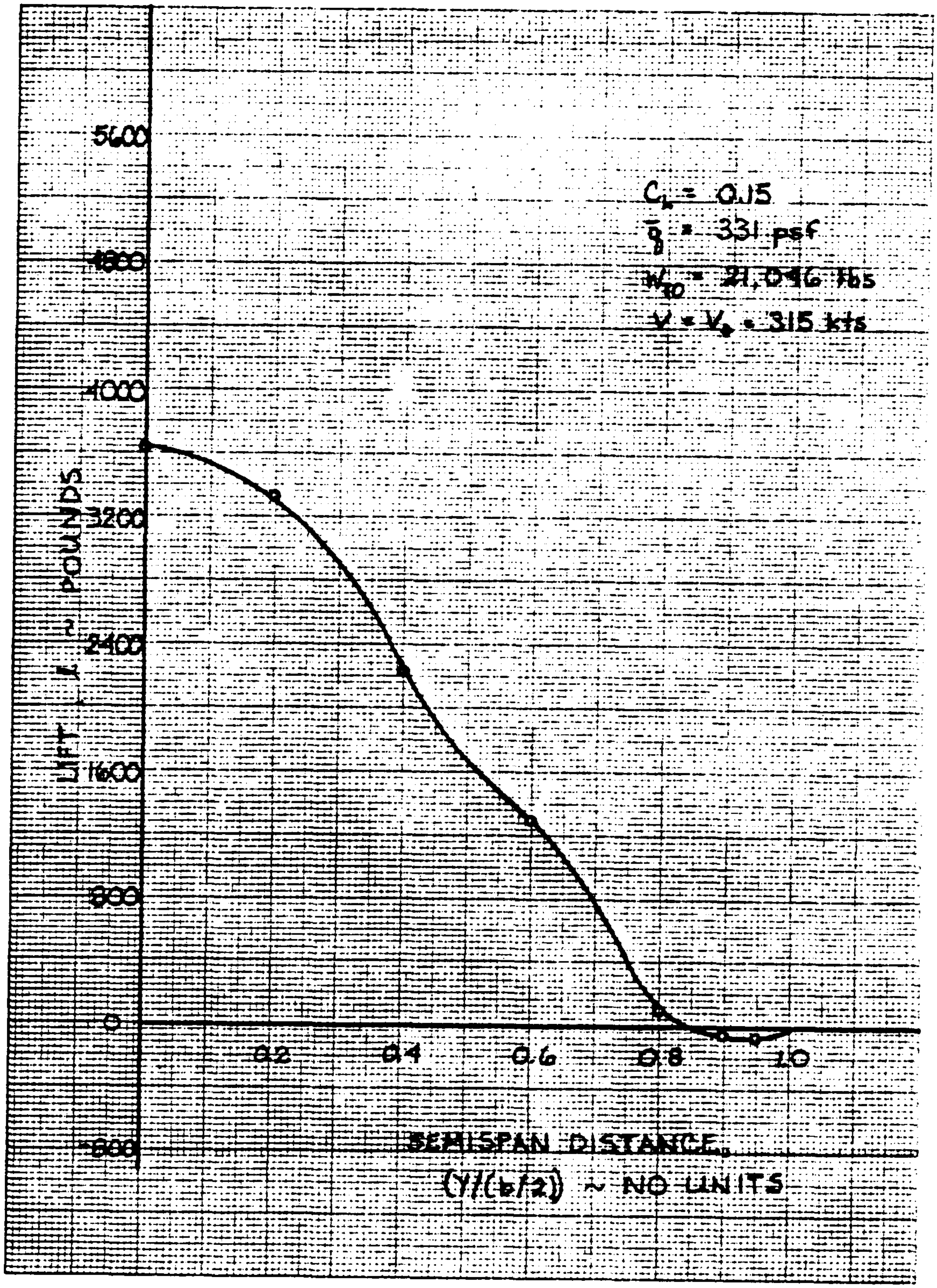

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Figure C.4 Load Diagram for 25 Pax Commuter at C_L = 0.15

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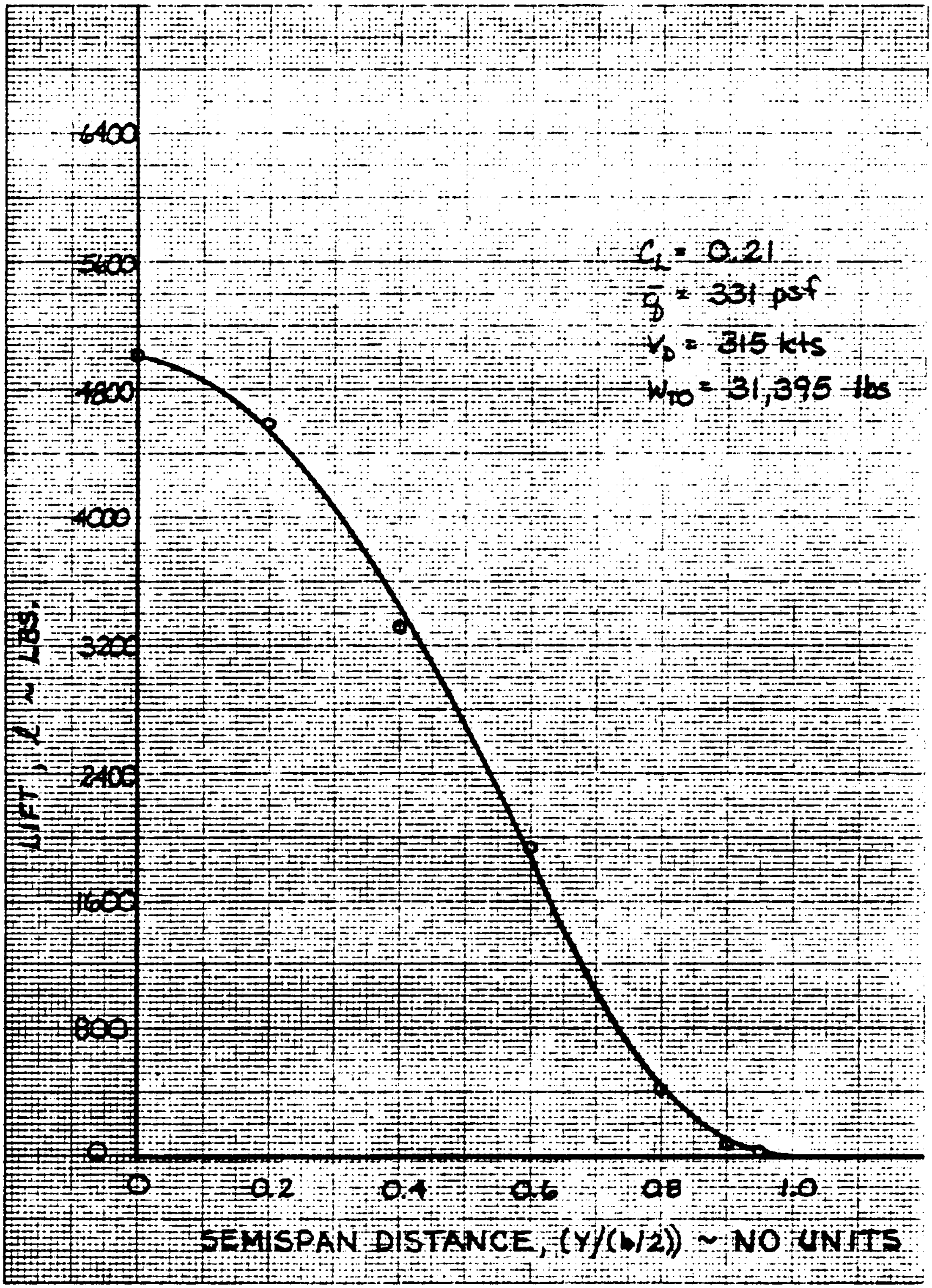

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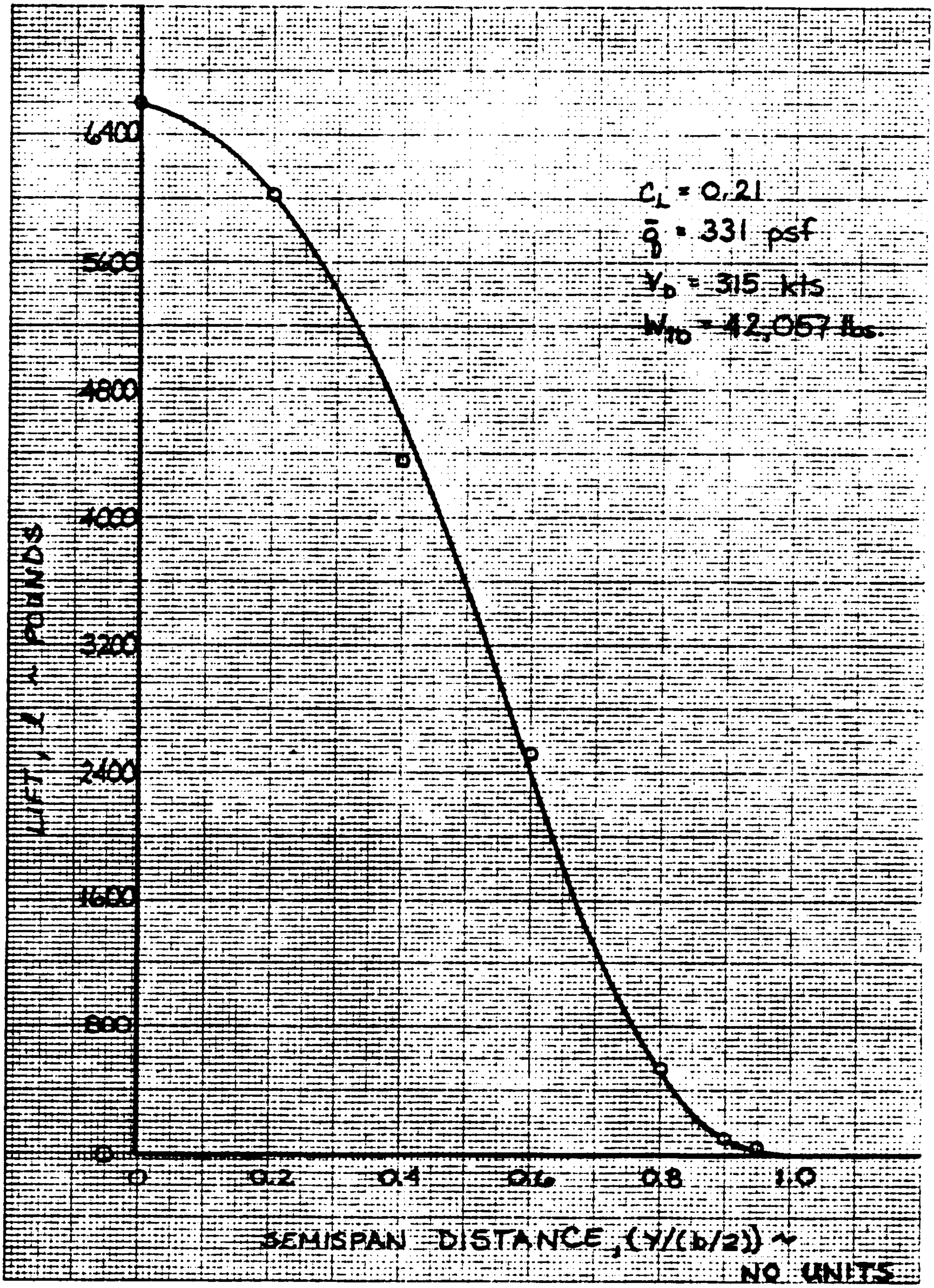

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Figure C.6 Load Diagram for 50 Pax Commuter at C_L = 0.21

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AT CLEAN $C_{L_{MAX}} = 1.5$, THE FOLLOWING LIFT DISTRIBUTIONS WERE CALCULATED.

Table C.1 25 Pax Lift Distribution at C_L = 1.5

Y/(b/2)	ΔS (ft²)	C_l	Δb (ft)	l/Δb (lbs/ft)	l (lbs)
0.0	56.5	1.48	7.11	394	2801
0.2	49.3	1.56	7.11	362	2574
0.4	42.1	1.56	7.11	309	2197
0.6	34.9	1.51	7.11	248	1763
0.8	14.7	1.38	3.56	191	680
0.9	6.69	1.20	1.78	151	269
0.95	6.24	1.01	1.78	119	212

$\bar{q}$ = 33.5 psf

$L_{b/2}$ = 10,253 lbs

W_{TO} = 21,046 lbs L_b = 20,506 lbs

Table C.2 36 Pax Lift Distribution at C_L = 1.5

Y/(b/2)	ΔS (ft²)	C_l	Δb (ft)	l/Δb (lbs/ft)	l (lbs)
0.0	60.3	1.48	7.34	567	4168
0.2	52.6	1.56	7.34	523	3832
0.4	44.9	1.56	7.34	446	3271
0.6	37.2	1.51	7.34	357	2624
0.8	15.7	1.38	3.67	276	1012
0.9	7.14	1.20	1.84	217	400
0.95	6.66	1.01	1.84	170	314

$L_{b/2}$ = 15,621 lbs

$\bar{q}$ = 46.7 psf

W_{TO} = 31,395 lbs L_b = 31,242 lbs

Table C.3 50 Pax Lift Distribution at C_L = 1.5

Y/(b/2)	ΔS (ft²)	C_l	Δb (ft)	l/Δb (lbs/ft)	l (lbs)
0.0	79.2	1.48	8.43	659	5556
0.2	69.0	1.56	8.43	605	5102
0.4	59.0	1.56	8.43	517	4362
0.6	48.8	1.51	8.43	414	3492
0.8	20.6	1.38	4.22	319	1348
0.9	9.37	1.20	2.11	252	533
0.95	8.74	1.01	2.11	198	418

$L_{b/2}$ = 20,811 lbs

$\bar{q}$ = 47.4 psf

W_{TO} = 42,057 lbs L_b = 41,623 lbs

AT V_D, C_L = 0.15, 0.21, 0.21 FOR THE 25, 36, AND 50 PAX, THE FOLLOWING LIFT DISTRIBUTIONS WERE CALCULATED.

TABLE C.4 -- 25 PAX LIFT AT C_L = 0.15.

Y/(b/2)	ΔS (ft²)	C_ℓ	Δb (ft)	ℓ/Δb (lbs/ft)	ℓ (lbs)
0.0	56.5	0.195	7.11	513	3647
0.2	49.3	0.204	7.11	468	3329
0.4	42.1	0.160	7.11	314	2230
0.6	34.9	0.095	7.11	154	1097
0.8	14.7	0.020	3.56	27.3	97
0.9	6.69	-0.024	1.78	-29.9	-53
0.95	6.24	-0.035	1.78	-40.6	-72

$\bar{q}$ = 331 psf

$L_{b/2}$ = 10,275

W_{TO} = 21,046 lbs L_b 20,550

TABLE C.5 -- 36 PAX LIFT AT C_L = 0.21.

Y/(b/2)	ΔS (ft²)	C_ℓ	Δb (ft)	ℓ/Δb (lbs/ft)	ℓ (lbs)
0.0	60.3	0.252	7.34	685	5030
0.2	52.6	0.264	7.34	626	4596
0.4	44.9	0.223	7.34	452	3314
0.6	37.2	0.158	7.34	265	1945
0.8	15.7	0.080	3.67	113	416
0.9	7.14	0.031	1.84	39.8	73
0.95	6.66	0.012	1.84	14.4	26

$\bar{q}$ = 331 psf

$L_{b/2}$ = 15400

W_{TO} = 31,395 lbs L_b = 30,800

TABLE C.6 -- 50 PAX LIFT AT C_L = 0.21.

Y/(b/2)	ΔS (ft²)	C_ℓ	Δb (ft)	ℓ/Δb (lbs/ft)	ℓ (lbs)
0.0	79.2	0.252	8.43	784	6606
0.2	69.0	0.264	8.43	715	6029
0.4	59.0	0.223	8.43	517	4355
0.6	48.8	0.158	8.43	303	2552
0.8	20.6	0.080	4.22	129	545
0.9	9.37	0.031	2.11	45.6	96
0.95	8.74	0.012	2.11	16.5	35

$\bar{q}$ = 331 psf

$L_{b/2}$ = 20,218 lbs

W_{TO} = 42,057 lbs. L_b = 40,436 lbs

At landing: (with W_{TO})

	25 PAX	36 PAX	50 PAX
$C_{L_{LAND}}$ =	2.2	3.0	3.0
$\bar{q}_L$ =	22.8	23.4	23.7 psf

Lift distributions:

Table C.7 25 Pax Lift Distribution at C_L = 2.2

Y/(b/2)	ΔS (ft²)	C_ℓ	Δb(ft)	ℓ/Δb (lbs/ft)	ℓ (lbs)
0	56.5	2.15	7.11	390	2770
.2	49.3	2.27	7.11	359	2552
.4	42.1	2.28	7.11	308	2189
.6	34.9	2.25	7.11	252	1790
.8	14.7	2.08	3.56	196	697
.9	6.69	1.84	1.78	157	281
.95	6.24	1.54	1.78	123	219

$L_{b/2}$ = 10,497 lbs

W_{TO} = 21,046 lbs L_b = 20,994 lbs

Table C.8 36 Pax Lift Distribution at C_L = 3.0

Y/(b/2)	ΔS	C_ℓ	Δb	ℓ/Δb	ℓ
0	60.3	2.91	7.34	560	4107
.2	52.6	3.07	7.34	515	3779
.4	44.9	3.11	7.34	445	3268
.6	37.2	3.09	7.34	366	2690
.8	15.7	2.89	3.64	292	1062
.9	7.14	2.57	1.84	233	429
.95	6.66	2.16	1.84	183	337

$L_{b/2}$ = 15,694 lbs

W_{TO} = 31,395 lbs L_b = 31,388 lbs

Table C.9 50 Pax Lift Distribution at C_L = 3.0

Y/(b/2)	ΔS	Cℓ	Δb	ℓ/Δb	ℓ
0	79.2	2.91	8.43	648	5462
.2	69.0	3.07	8.43	596	5020
.4	59.0	3.11	8.43	516	4349
.6	48.8	3.09	8.43	424	3574
.8	20.6	2.89	4.22	334	1411
.9	9.37	2.57	2.11	270	571
.95	8.74	2.16	2.11	212	447

$L_{b/2}$ = 20,834 lbs

W_{TO} = 42,057 lbs L_b = 41,668 lbs

Table C.10 Shear, Moment, and Inertia Equations

1. STATION : $ST = y/(b/2)$ (MEASURED FROM CENTERLINE)
2. LOAD: P = LOAD FROM TABLES -1, -2, -3.
3. SHEAR: V = SUM OF OUTBOARD LOADS AT EACH SPANWISE STATION.
4. SECTION WIDTH: dY = SECTIONAL WIDTH AT EACH STATION.
5. D_i : $D_i = (dY)\,0.48$
6. $V \times dY$: $V \times dY$ = COL. $3_{n-1} \times$ COL. 4_n
7. $P \times D_i$: $P \times D_i$ = COL. 2 × COL. 5
8. M_x : M_x = COL 6 + COL 7
9. X_i : X_i = DISTANCE OF SECTIONAL AC TO THE REFERENCE AXIS (DRAWN THROUGH AFT CG)
10. $P \times X_i$: $P \times X_i$ = COL. 2. × COL 9
11. M_y : $M_y = \Sigma$ COL 10 (OUTBOARD MOMENT AT EACH SECTION)
12. $FS \times M_x$: $FS \times M_x = 1.5 \cdot$ COL. 8
13. $FS \times M_y$: $FS \times M_y = 1.5 \cdot$ COL 11
14. CHORD: CHORD = ACTUAL CHORD LENGTH AT EACH SECTION.
15. Z_f : $Z_f = (0.90 \cdot \text{THICKNESS})/2$ [AT FRONT SPAR LOCATION]
16. Z_r : $Z_r = (0.90 \cdot \text{THICKNESS})/2$ [AT REAR SPAR LOCATION]
17. Z_{ave} : $Z_{ave} = \frac{1}{2}(Z_f + Z_r)$
18. I_{xx} (one spar cap): $I_{xx}\ (\text{in}^4) = \frac{M_x Z}{\sigma} = 2.5(\text{COL. 8} \times \text{COL 17})(144)/(55000 \cdot 4)$

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Table C.11 Spar and Web Areas and Weight Equations

SPAR AREA - FROM $I_{xx} = 4\left[I_{xx_o} + A_o Z_{o_{ave}}^2 \right]$.

From Table A3.12 of Bruhn, $I_{xx_o} \approx .3908 A_o - .0408$.

Thus, $A_o = \dfrac{I_{xx}/4 + .0408}{.3977 + Z_{o_{ave}}^2}$

SPAR WEIGHT $W_S = [(\text{Spar Area} \times \text{Section width}) \times \text{Density}]$

$= [(\text{Area} \times \text{Width}) \times 174.8]$

SHEAR FLOW $q = \dfrac{V}{h} = \dfrac{V}{2Z_{ave}}$

Web Thickness $t = \dfrac{q}{\sigma} = \dfrac{q}{55,000}$

Web Area $A_w = h \times t = 2Z_{ave} \times t$

Web Weight $W_{web} = A_w \times \text{width of section} \times 174.8$

Total web + spar weight $W_T = W_S + W_{web}$

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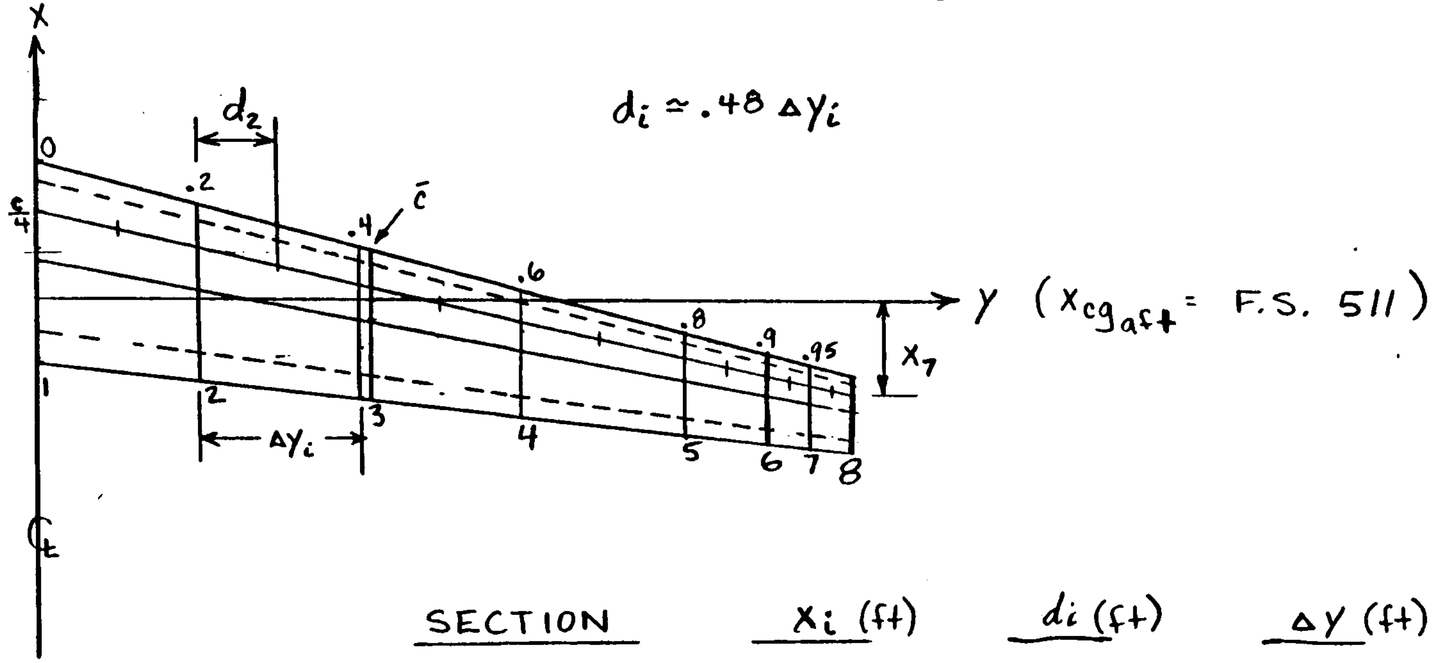
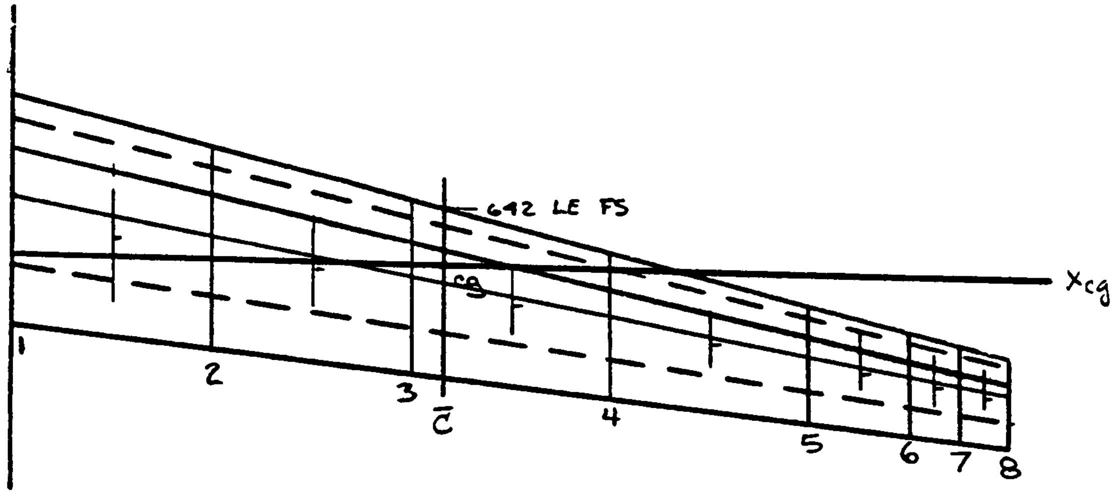


SECTION	x_i (ft)	d_i (ft)	Δy (ft)
1	3.00	3.41	7.11
2	1.42	3.41	7.11
3	-.25	3.41	7.11
4	-1.67	3.41	7.11
5	-2.83	1.71	3.56
6	-3.50	.854	1.78
7	-3.83	.854	1.78

FIGURE 7 **Sectional Geometry for 25 Pax Wing**



$S = 591\ Ft^2$
$A = 12$
$b = 84.2\ Ft$
$C_r = 10.0\ Ft$
$\lambda = 0.4$

F.S. = 0.10 C
R.S. = 0.75 C

50 PASSENGER COMMUTER

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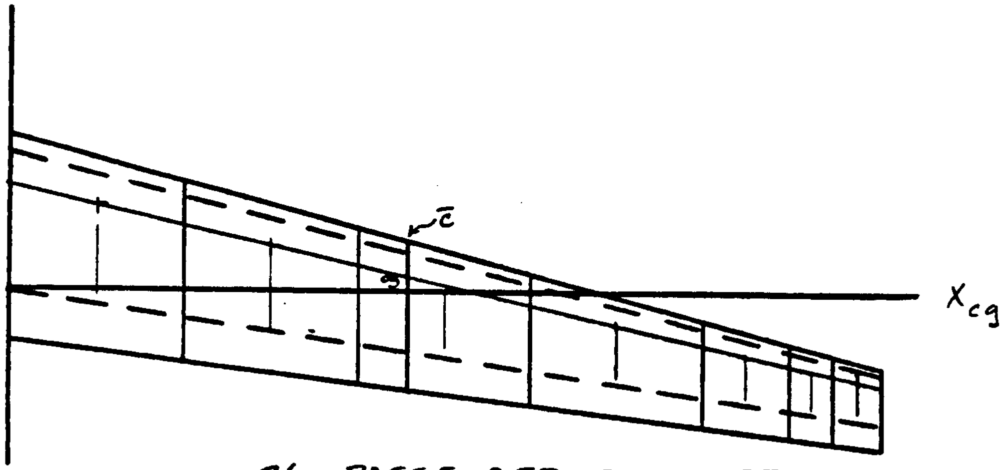

$S = 449\ Ft^2$
$A = 12$
$b = 73.4\ ft$
$C_r = 8.74\ Ft$
$\lambda = 0.4$

F.S. = 0.08 c
R.S. = 0.75 c

36 PASSENGER COMMUTER

Figure C.8 Sectional Geometry for 36 and 50 Pax Wings

Table C.12 25 Pax Spar Sizing Calculations

Section	Station y/(b/2)	P Load (lbs)	V Shear (lbs)	dY Width (ft)	Di (ft)	VxdY (ft-lbs)
8	1	0	0	0	0	0
7	.95	-72	-72	1.78	.85	0
6	.9	-53	-125	1.78	.85	-128
5	.8	97	-28	3.56	1.71	-445
4	.6	1097	1069	7.11	3.41	-199
3	.4	2230	3299	7.11	3.41	7601
2	.2	3329	6628	7.11	3.41	23456
1	0	3647	10275	7.11	3.41	47125

PxDi (ft-lbs)	Mx X-Moment (ft-lbs)	Xi (ft)	PxXi (ft-lbs)	My Y-Moment (ft-lbs)	FSxMx (ft-lbs)	FSxMy (ft-lbs)
0	0	0	0	0	0	0
-61	-61	-3.83	276	276	-92	414
-45	-234	-3.5	186	462	-351	693
166	-513	-2.83	-275	187	-770	281
3741	3029	-1.67	-1832	-1645	4544	-2468
7604	18234	-.25	-558	-2203	27351	-3305
11352	53042	1.42	4727	2524	79563	3786
12436	112603	3	10941	13465	168905	20198

Chord (ft)	Zf (ft)	Zr (ft)	Zave (ft)	Ixx/4 (in^4)	Section Spar Area (in^2)	Spar Weight (lbs)
3.39	.185	.176	.181	.000		.00
3.5	.191	.181	.186	.028	.013	.03
3.83	.209	.198	.204	.117	.025	.05
4.5	.245	.233	.239	.301	.040	.17
5.33	.29	.276	.283	2.104	.180	1.55
6.33	.345	.328	.337	15.061	.904	7.80
7.5	.409	.389	.399	51.948	2.229	19.24
8.46	.461	.438	.450	124.239	4.214	36.37
				Weight of one spar		65.22

Shear Flow (lbs/in)	Web Thickness (in)	Web Area (in^2)	Web Weight (lbs)	Total web + spar weight (lbs)
.00	.000	.000	.000	0
-24.19	.000	.000	.000	.1
-38.39	.001	.005	.000	.2
-7.32	.000	.000	.000	.7
236.09	.004	.027	.006	6.2
612.74	.011	.089	.097	31.4
1038.22	.019	.182	.492	77.9
1428.67	.026	.280	1.435	148.3
		TOTALS:	2.030	264.9

Table C.13 36 Pax Spar Sizing Calculations

Section	Station y/(b/2)	P Load (lbs)	V Shear (lbs)	dY Width (ft)	Di (ft)	VxdY (ft-lbs)
8	1	0	0	0	0	0
7	.95	26	26	1.84	.88	0
6	.9	73	99	1.84	.88	48
5	.8	416	515	3.67	1.76	363
4	.6	1945	2460	7.34	3.52	3780
3	.4	3314	5774	7.34	3.52	18056
2	.2	4596	10370	7.34	3.52	42381
1	0	5030	15400	7.34	3.52	76116

PxDi (ft-lbs)	Mx X-Moment (ft-lbs)	Xi (ft)	PxXi (ft-lbs)	My Y-Moment (ft-lbs)	FSxMx (ft-lbs)	FSxMy (ft-lbs)
0	0	0	0	0	0	0
23	23	-3.83	-100	-100	35	-150
64	135	-3.33	-243	-343	203	-515
732	1230	-2.5	-1040	-1383	1845	-2075
6846	11856	-1.5	-2918	-4301	17784	-6452
11665	41577	.25	829	-3472	62366	-5208
16178	100136	2	9192	5720	150204	8580
17706	193958	3.67	18460	24180	290937	36270

Chord (ft)	Zf (ft)	Zr (ft)	Zave (ft)	Ixx/4 (in^4)	Spar Area (in^2)	Section Spar Weight (lbs)
3.5	.184	.175	.180	.000	.000	.00
3.92	.207	.197	.202	.011	.008	.02
4.17	.22	.209	.215	.071	.016	.04
4.58	.241	.23	.236	.711	.090	.40
5.75	.303	.288	.296	8.600	.666	5.93
6.83	.36	.342	.351	35.821	1.977	17.61
7.83	.413	.393	.403	99.055	4.166	37.12
8.74	.461	.438	.450	214.001	7.257	64.66
					Weight of one spar	125.78

Shear Flow (lbs/in)	Web Thickness (in)	Web Area (in^2)	Web Weight (lbs)	Total web + spar weight (lbs)
.0	.000	.000	.00	0
8.0	.000	.000	.00	.1
28.8	.001	.005	.00	.1
136.7	.002	.011	.00	1.6
520.3	.009	.064	.05	23.8
1028.1	.019	.160	.38	71.2
1608.3	.029	.280	1.42	151.3
2141.3	.039	.421	3.71	266.1
		TOTALS:	5.56	514.3

Table C.14 50 Pax Spar Sizing Calculations

Section	Station y/(b/2)	P Load (lbs)	V Shear (lbs)	dY Width (ft)	Di (ft)	VxdY (ft-lbs)
8	1	0	0	0	0	0
7	.95	35	35	2.11	1.01	0
6	.9	96	131	2.11	1.01	74
5	.8	545	676	4.22	2.03	553
4	.6	2552	3228	8.33	4	5631
3	.4	4355	7583	8.33	4	26889
2	.2	6029	13612	8.33	4	63166
1	0	6606	20218	8.33	4	113388

PxDi (ft-lbs)	Mx X-Moment (ft-lbs)	Xi (ft)	PxXi (ft-lbs)	My Y-Moment (ft-lbs)	FSxMx (ft-lbs)	FSxMy (ft-lbs)
0	0	0	0	0	0	0
35	35	-4.33	-152	-152	53	-228
97	206	-3.92	-376	-528	309	-792
1106	1865	-3.33	-1815	-2343	2798	-3515
10208	17704	-1.83	-4670	-7013	26556	-10520
17420	62013	0	0	-7013	93020	-10520
24116	149295	1.83	11033	4020	223943	6030
26424	289107	3.75	24773	28793	433661	43190

Chord (ft)	Zf (ft)	Zr (ft)	Zave (ft)	Ixx/4 (in^4)	Section Spar Area (in^2)	Section Spar Weight (lbs)
4	.185	.176	.18	.00	.00	.00
4.17	.193	.184	.19	.02	.01	.03
4.67	.216	.206	.21	.11	.02	.06
5.17	.24	.228	.23	1.07	.13	.69
6.42	.298	.283	.29	12.62	1.01	10.20
7.58	.351	.334	.34	52.13	3.02	30.52
8.83	.409	.389	.40	146.22	6.27	63.41
10	.464	.441	.45	321.11	10.75	108.67
					Weight of one spar	213.57

Shear Flow (lbs/in)	Web Thickness (in)	Web Area (in^2)	Web Weight (lbs)	Total web + spar weight (lbs)
0	0	.000	.00	0
12	0	.000	.00	.11
39	.001	.005	.00	.23
181	.003	.017	.00	2.75
694	.013	.091	.11	41.03
1384	.025	.206	.75	123.57
2132	.039	.373	2.84	259.33
2793	.051	.554	7.23	449.13
		TOTALS:	10.94	876.15

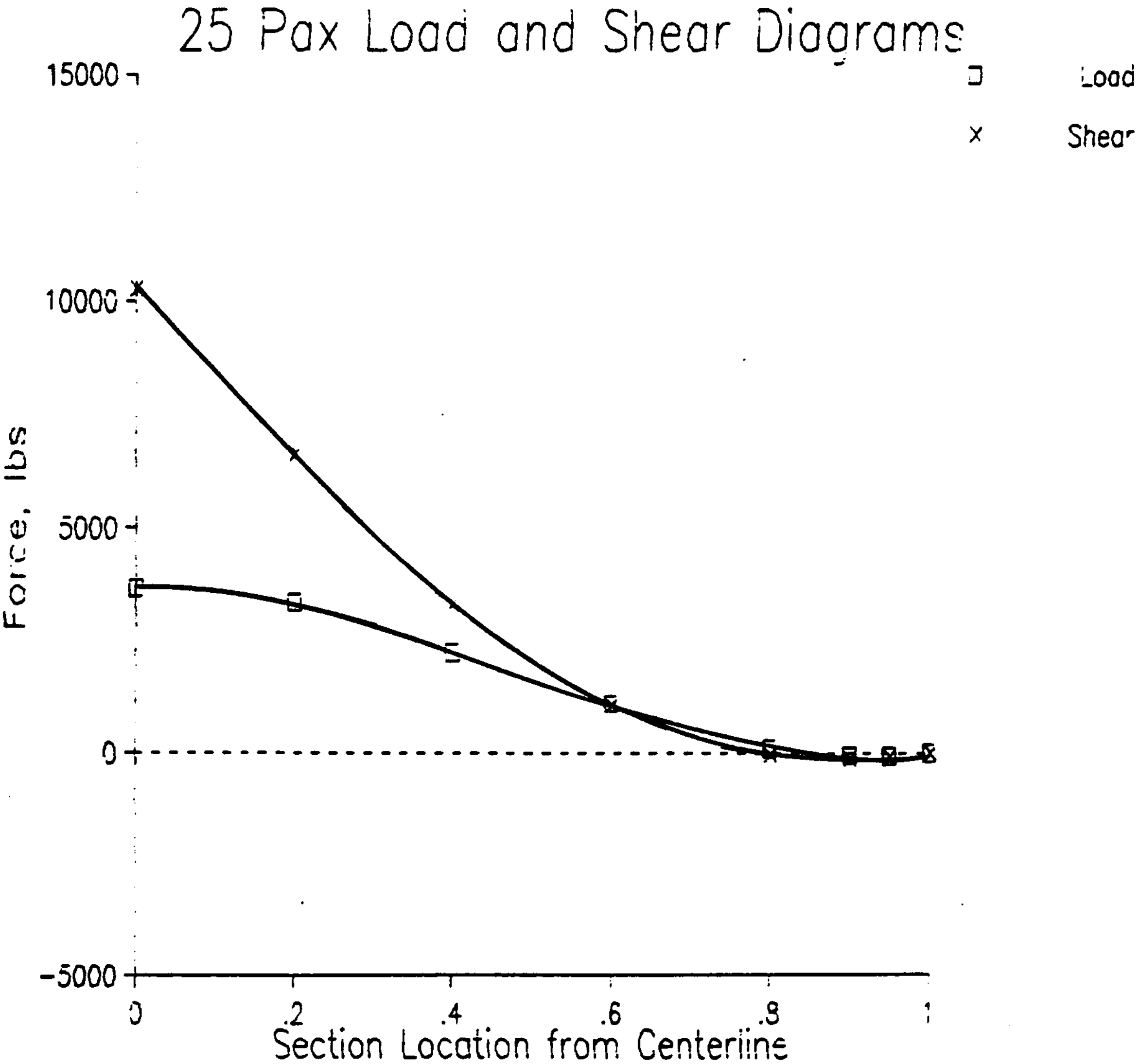

Figure C.9 25 Pax Load and Shear Diagrams

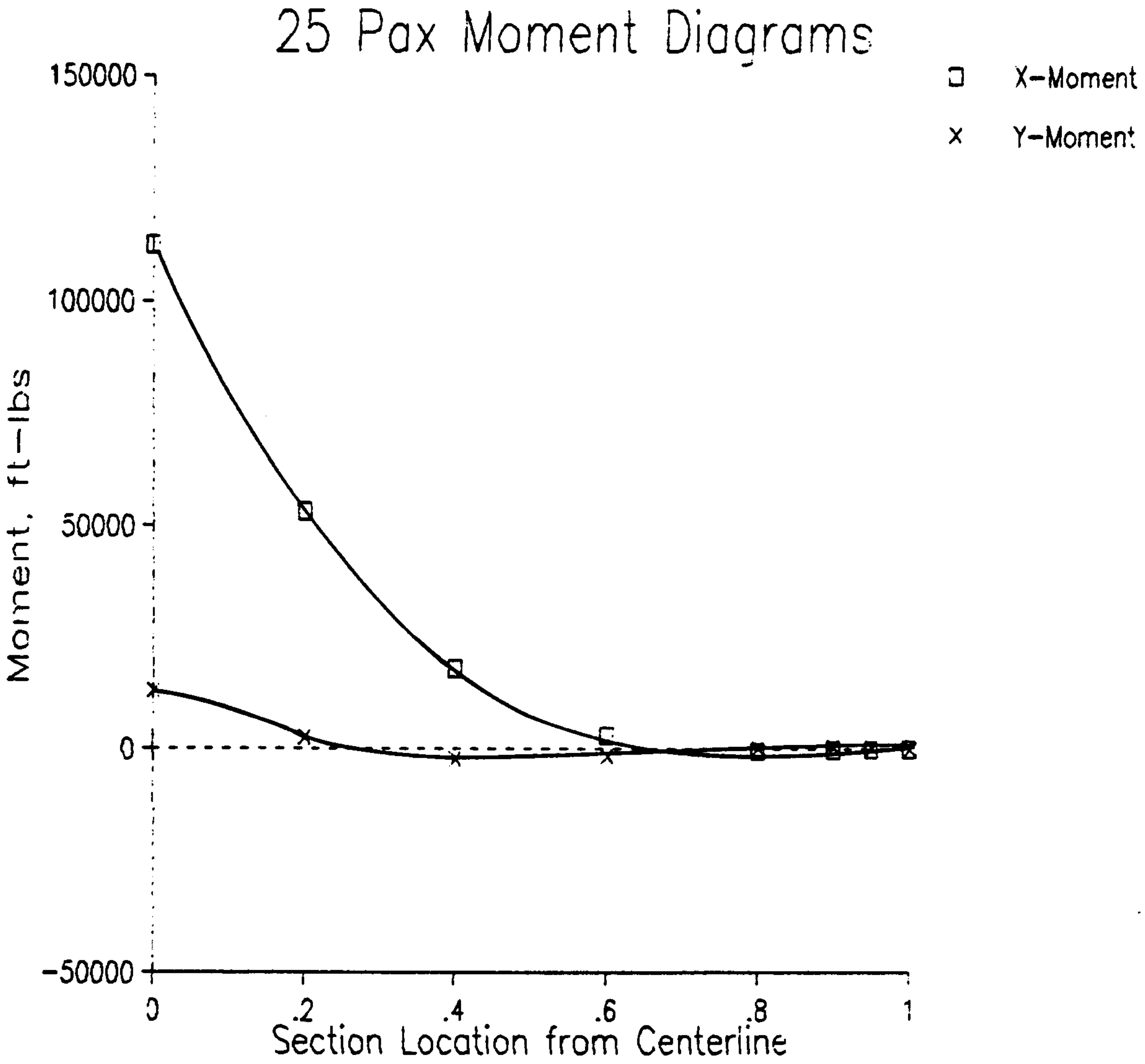

Figure C.10 25 Pax Moment Diagrams

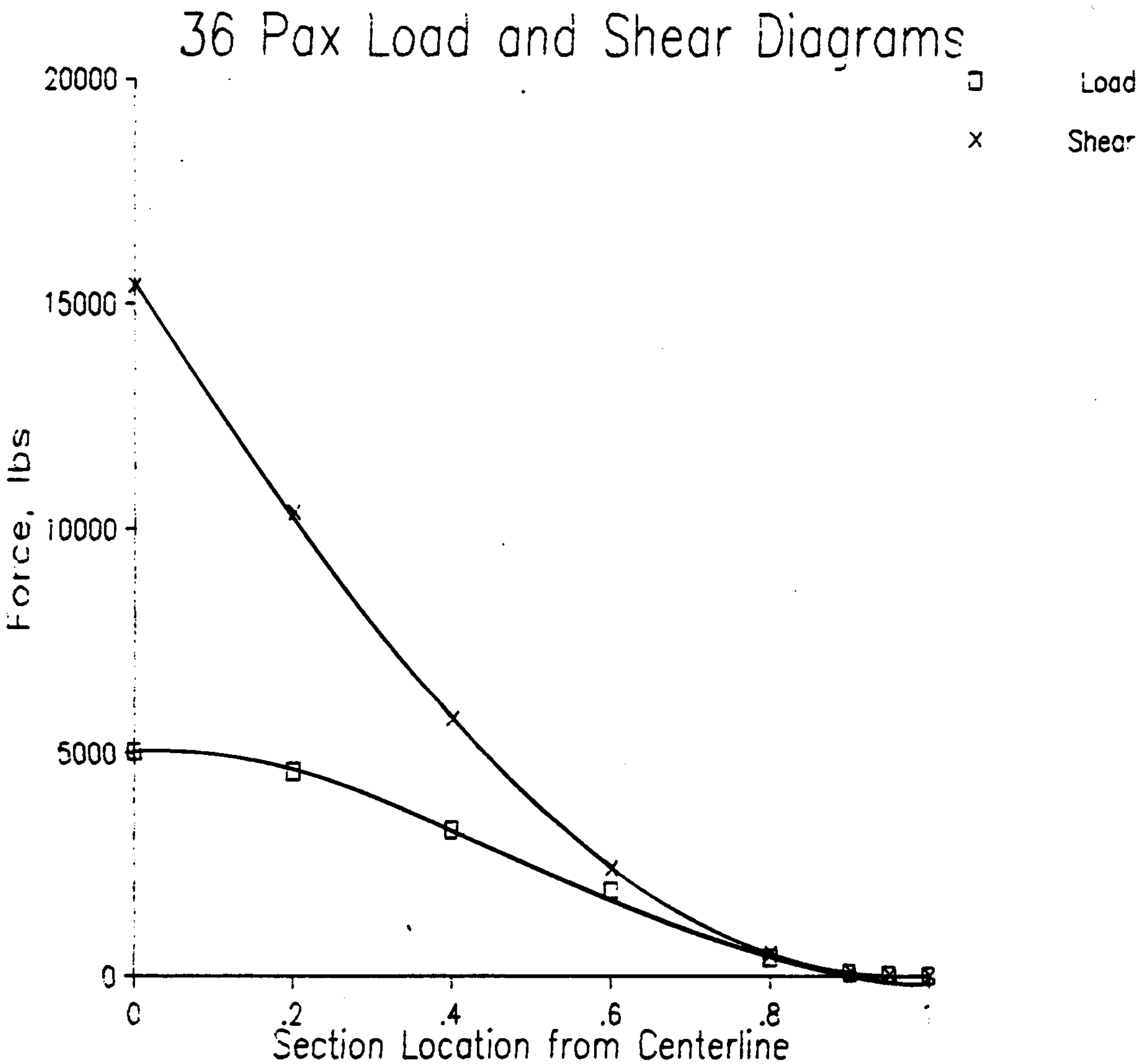

Figure C.11 36 Pax Load and Shear Diagrams

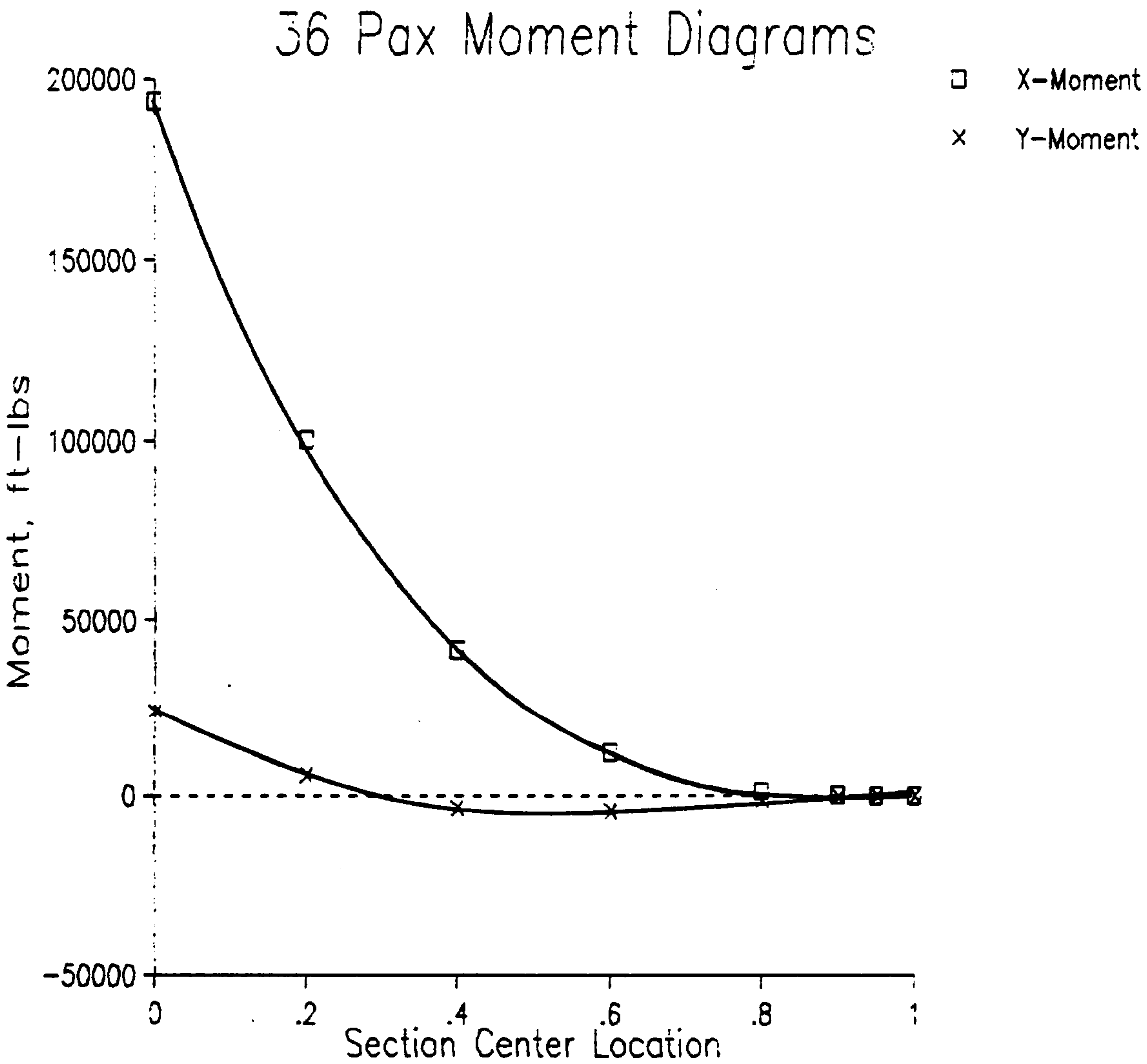

Figure C.12 36 Pax Moment Diagrams

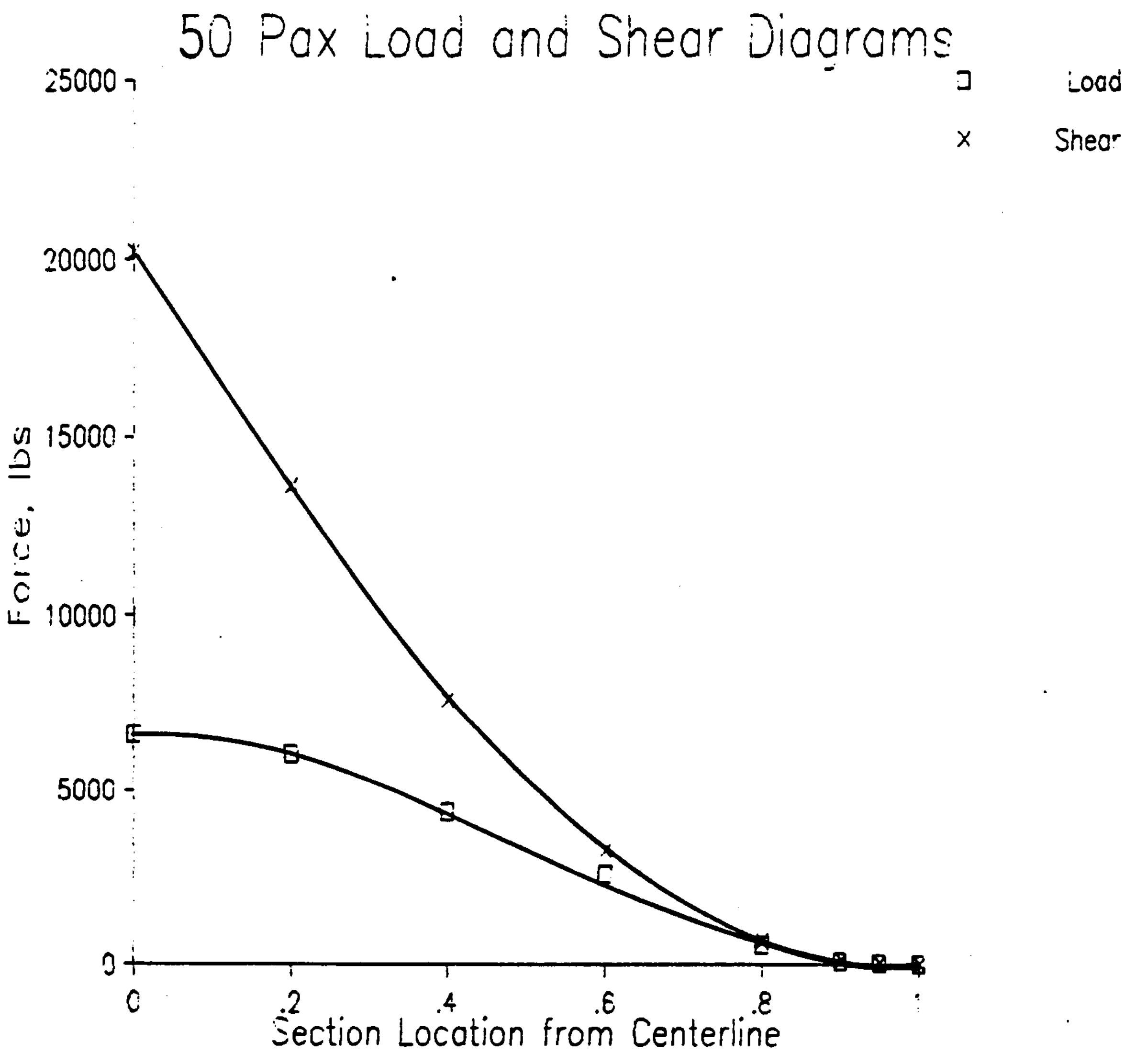

Figure C.13 50 Pax Load and Shear Diagrams

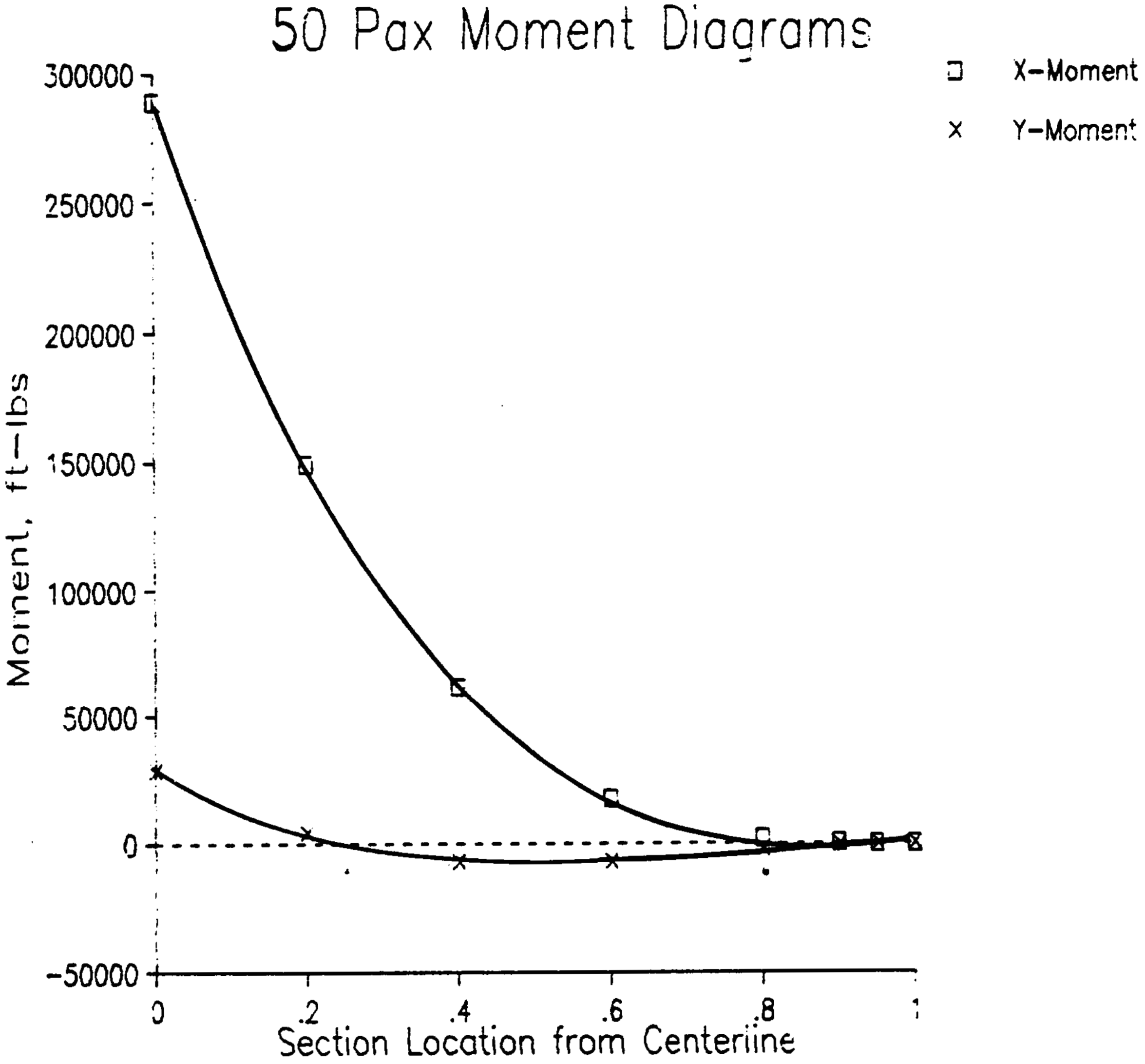

Figure C.14 50 Pax Moment Diagrams

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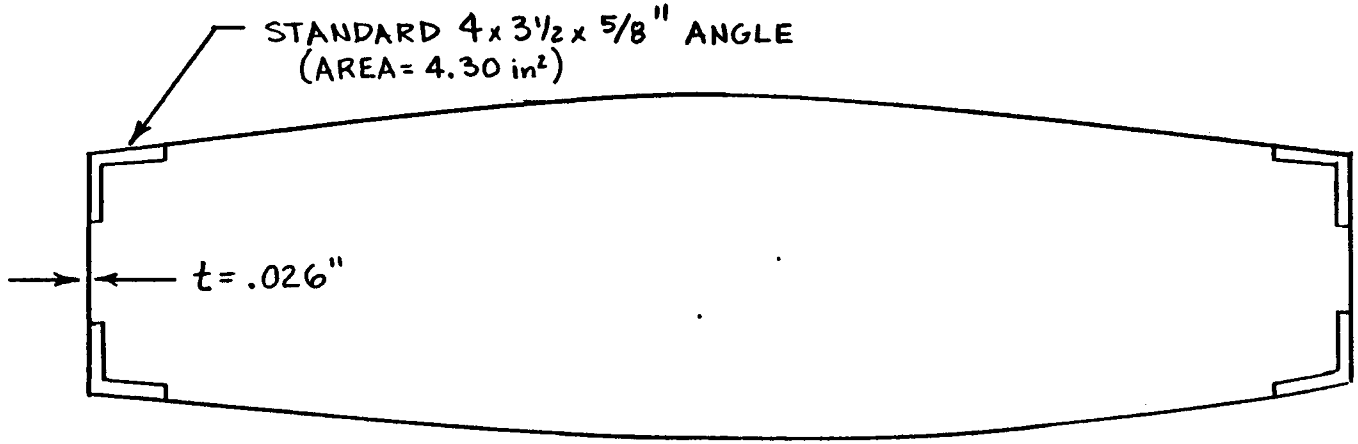

Figure C.15 25 Pax Root Section Torque Box

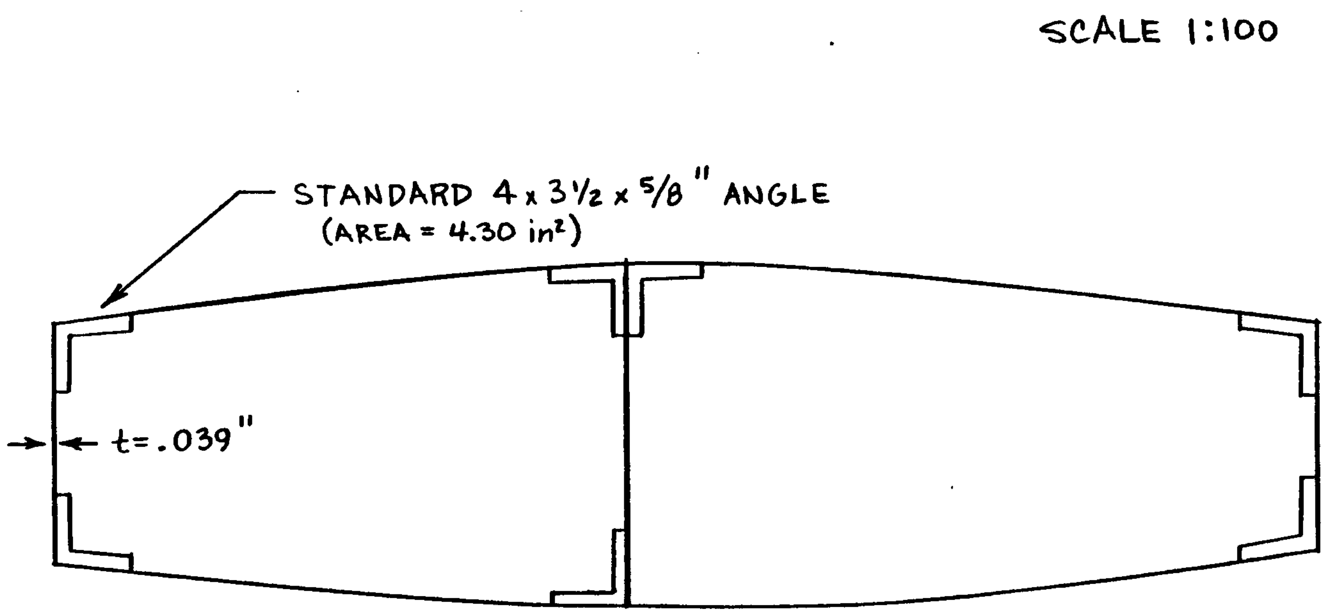

Figure C.16 36 Pax Root Section Torque Box.

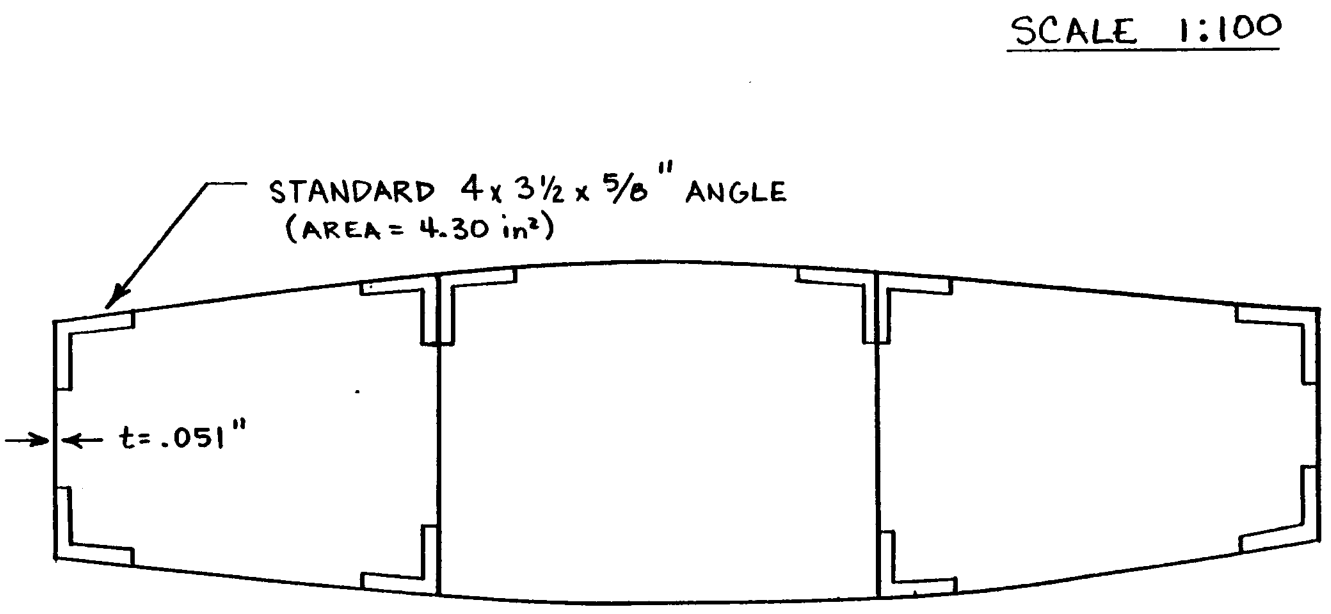

Figure C.17 50 Pax Root Section Torque Box

List of Symbols

SYMBOL	DEFINITION	UNITS
ax/g	Forward Deceleration/gravity constant	
c.g.	Center of gravity	
Do	Outside tire diameter	inch
Dstrut	Strut diameter	ft.
ESWL	Equivalent Single Wheel Load	lb
Et	Kinetic Energy	ft-lb
h_{cg}	Ground to c.g. distance	in.
lm	Main gear to c.g. distance	in
ln	Nose gear to c.g. distance	in
nt	Tire absorbtion efficiency	
Pm	Main gear static load	lb
Pn	Nose gear static load	lb
St	Loaded tire deflection	inch
Ss	Shock stroke length	ft.
W	Tire width	inch.
WTO	Take-off weight	lb.

Appendix D: Class II Landing Gear Analysis

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Class II Landing Gear Analysis

This appendix presents the Class II analysis of the landing gear for the family of commuter transports. An optimization versus commonality study was also completed.

The design considerations in choosing tires and strut layout are:

*Size of main gear stowage volume limited due to drag penalties.

*Available stowage volume for nose gear limited by fuselage shape.

*Desire to keep the LCN values for the airplanes low. Forced the tire pressures to remain low.

The drag due to the fairing needed to store the main landing gear must be kept as low as possible. This required that the tires have as small a diameter and thickness as possible.

The size of the fuselage forced the nose gear tires to be less than 30 inches by 9 inches.

The Fokker F-28 has a LCN of 27. It is desirable to be able to have the 50 Pax airplane to operate out of the same airports as does the F-28. This required the tire pressures to be as low as possible. This consideration is believed to outway any of the above considerations.

Step 1 Determine the maximum loads, critical static loads, which exist on the landing gear struts. the loads occured in the take-off configuration for all of the airplanes. Table I and II contains the results.

NOTE: All calculations were carried out in accordance with the methods contained in Reference 4.

Step 2 The tire loads were calculated accounting for federal regulations and growth of the airplane. The following tire/strut arrangements were analyzed:

Both twin body airplanes have two nose gear struts.

*Tricycle, dual tire arrangement on all airplanes

*4 main struts, dual tire arrangement for the 75 and 100 Pax (Dual Main)

*2 main struts, dual tandem tire arrangement for the 50, 75 and 100 Pax (Dual Tandem)

The loads per tire and the equivalent single wheel loads, ESWL, were calculated and are contained in Table III.

Step 3 From the design static loads of Table III and the limit pressures gained from the ESWL values, tires were choosen for each airplane for optimization analysis. Table IV contains a listing of the tires chosen. From this listing a common nose gear tire was chosen as well as a common main gear tire. The reason for choosing a common nose gear tire is that the common main gear tire would not fit in the allowable space for the nose gear tire. This was due to the shape of the fuselage.

Step 4 Strut sizing was done for each airplane for optimization analysis. The struts choosen for commonality are based on one of two choices. The common nose gear strut is based on the nose gear for the 50 Pax. The common main gear struts can be based on the 50 Pax or the 100 Pax in the two strut with dual tandem tire arrangement configuration. Table V contains the strut sizing analysis. Step 5 discusses the weight penalties resulting from commonality.

Step 5 An optimization/commonality weight analysis was done using the Class II weight procedures of Reference 5, Equation 5.42. Table VI contains the results.

To obtain a weight for the 75 and 100 Pax airplanes using the four main struts with dual tires the weights of the 36 and 50 Pax were doubled. For the 75 and 100 in the dual tandem configuration Equation 5.43, Reference 5, was applied directly to the airplanes.

Table VI lists the optimized weights for each airplane and then lists the weight penalties incurred by using common nose and main gear struts. It shows the penalties resulting from using either the 50 Pax main gear or the two strut, dual tandem 100 Pax configuration main gear strut for the common main gear strut. The weight penalties for the nose gears are based on the nose gear for the 50 Pax.

Appendix D: Conclusions

The required size of the tires for the 100 Pax, two main strut, dual tire configuration is considered prohibitive for stowage volume reasons.

The limited space available for stowing the nose gear prohibits the use of a common tire for both the main and the nose gear. It is necessary to use a common nose gear tire and a common main gear tire.

The results of the Class II weight analysis suggests that the dual tire, four main strut configuration for the 75 and 100 Pax airplanes is the only viable configuration for these airplanes, if common landing gear struts are to be used. The weight penalties are just to great for the use of any other configuration.

The greatest weight penalty for implementing the 50 Pax gear was 769 lbs. This penalty occurred on the 25 Pax configuration.

Using main gear struts for nose gear struts was not considered due to the fact that even for the 50 Pax the resulting weight penalty would be about 500 lbs.

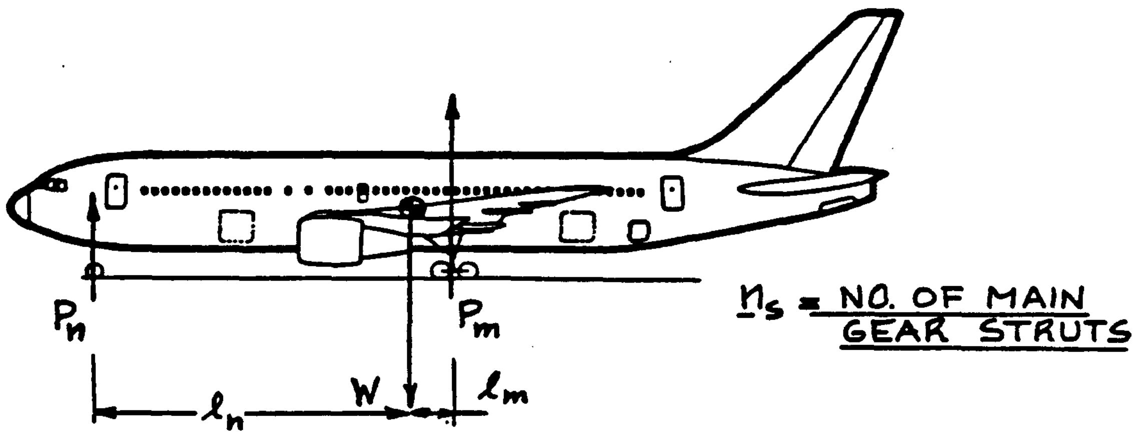
Appendix D: Recommendations

If common landing gear struts are to be used the struts optimized for the 50 Pax should be used. However, the best arrangement would be to use a common nose gear strut and use optimized main gear struts to get the best blend of commonality and weight savings. The cost in payload is considered to be too great by using common main gear struts. A common brake assembly may be possible but this consideration is beyond the scope of this report.

Due to the common maintenance requirements associated with tires, it is very desireable to use a common tire as much as possible among the gear. This use of a common tire would ease maintenance and minimize inventory cost.

TABLE 1: Critical Static Loads

Airplane		Weight (lb)	C.G. X(in)	lm (in)	Pm (in)	ln (in)	Pn (in)
25 Pax	Take-off	21046	502	48	8839	252	3367
36 Pax	Take-off	31395	579	41	14397	454	2600
50 Pax	Take-off	42057	662	58	18589	442	4879
75 Pax (Dual Tandem)	Take-off	60683	587	53	26728	392	3614
75 Pax (Dual Main)	Take-off	60683	587	53	13364	392	3614
100 Pax (Dual Tandem)	Take-off	80716	666	54	35999	446	4359
100 Pax (Dual Main)	Take-off	80716	666	54	18000	446	4359



Definition of P_m and P_n

TABLE II: Design Strut Loads

Airplane:	25Pax	36Pax	50Pax	Twin/Dual Tandem 75Pax	Twin/Dual Tandem 100Pax	Dual Main 75Pax	Dual Main 100Pax
Critical							
Pm	8839	14397	18589	26728	35999	13364	18000
Pn	3367	2600	4879	3614	4359	3614	4359
Pn dynamic	3783	4097	5392	4844	4922	4844	4922
Pn static	2522	2731	3594	3230	3281	3230	3281
Pm FAR-25	9458	15405	19890	28599	38519	14300	19260
Pn FAR-25	3603	2782	5221	3867	4664	3867	4664
Pn Growth	4504	3478	6526	4834	5830	4834	5830
Design Maximum Static							
Pm	11822	19256	24863	35749	48149	17874	24075
Pn	4504	3478	6526	4834	5830	4834	5830

Pn dynamic = $WTO\{lm + ax/g(h_{cg})\} / nt(lm + ln)$

Pn static = (Pn dynamic) / 1.5

Pm FAR-25 = Pm x 1.07

Pn FAR-25 = Pn x 1.07

Pn Growth = (Pn FAR-25) x 1.25

TABLE III: Tire Sizing Loads

Airplane	Design Max. Static Pm(lb)	Pn(lb)	Load/Tire Pm(lb)	Pn(lb)	ESWL Main(lb)	Nose(lb)
25 Pax	11822	4504	5911	2252	8889	3386
36 Pax	19256	3478	9628	1739	14478	2615
50 Pax	24863	6526	12432	3263	18694	4907
50 Pax (Dual Tandem)	24863	6526	6216	3263	12432	4907
75 Pax	35749	4834	17875	2417	26879	3635
75 Pax (Dual Tandem)	35749	4834	8937	2417	17875	3635
75 Pax (Dual Main)	17874	4834	8937	2417	13439	3635
100 Pax	48149	5830	24074	2915	36201	4383
100 Pax (Dual Tandem)	48149	5830	12037	2915	24075	4383
100 Pax (Dual Main)	24075	5830	12038	2915	18102	4383

TABLE IV: Tire Choices for Main and Nose Gear

Nose Gear

Airplane	Type	Do x W (in.)	Max. Load (lb)	Pressure (psi)
25 Pax	VII	16 x 4.4	2300	120
36 Pax	VII	18 x 4.4	2100	100
50 Pax	ND	17.5 x 6.25-6	3750	90
75 Pax	VII	18 x 5.5	3050	105
100 Pax*	VII	18 x 5.5	3050	105

Main Gear

Airplane	Type	Do x W (in)	Loaded Radius (in)	Max. Load (lb)	Pressure (psi)
25 Pax	ND	29 x 11-10	11.4	7040	60
36 Pax	ND	26 x 10-11	10.25	9700	110
50 Pax	ND	H31 x 13-12	12.4	17200	155
50 Pax (Dual Tandem)	ND	22 x 8-10	9	6500	110
75 Pax	VII	34 x 11	13.9	18300	165
75 Pax (Dual Tandem)	ND	26 x 10-11	10.25	9700	110
75 Pax (Dual Main)	ND	26 x 10-11	10.25	9700	110
100 Pax	ND	37 x 14-14	15.1	25000	160
100 Pax (Dual Tandem)	ND	H31 x 13-12	12.4	17200	155
100 Pax* (Dual Main)	ND	H31 x 13-12	12.4	17200	155

* Commonality tire choice.

TABLE V: Main Gear Shock and Strut Sizing

Airplane:	25	36	50	75 Pax Twin	75 Pax Dual	75 Pax Tandem	100 Pax Twin	100 Pax Dual	100 Pax Tandem
Individually Optimized									
Et ft.lb$\times 10^4$	4.7	7.0	9.4	13.6	13.6	13.6	18.0	18.0	18.0
St (in)	6.2	5.5	6.2	6.2	5.5	5.0	6.8	6.2	6.2
Ss (ft)	1.36	1.26	1.28	1.28	1.32	1.34	1.23	1.26	1.26
Ss_{design}	1.44	1.34	1.36	1.36	1.40	1.42	1.31	1.34	1.35
Dstrut, ft	.313	.388	.435	.514	.375	.514	.590	.429	.590
Common Tire (St = 6.2 in)									
Ss_{design}	1.44	1.30	1.36		1.36	1.37		1.34	1.35
Dstrut, ft	.313	.388	.435		.375	.514		.429	.590

Twin: Two main gear with two tires per strut.

Dual: Four main gear with two tires per strut.

Tandem: Two main gear with four tires per strut in dual tandem.

TABLE VI: Weight Comparison

Airplane	Optimized Gear Weights Nose	Optimized Gear Weights Main	Common Gear Weight Selections Nose	Common Gear Weight Selections Main[1]	Common Gear Weight Selections Main[2]	Commonality Penalty Nose	Commonality Penalty Main[1]	Commonality Penalty Total[1]
25 Pax	201	765	290	1438	2684	89	673	762
36 Pax	267	1097	290	1438	2684	23	341	364
50 Pax	290	1438	290	1438	2684	0	0	0
75 Pax (Dual Tandem)	534	2036	580	N/A	2684	46	N/A	N/A
75 Pax (Dual Main)	534	2194	580	2876	N/A	46	682	728
100 Pax (Dual Tandem)	580	2684	580	N/A	2684	0	N/A	N/A
100 Pax (Dual Main)	580	2876	580	2876	N/A	0	0	0

1: Based on commonality with the 50 Pax.

2: Based on Commonality with the 100 Pax. Dual Tandem

N/A: Not Applicable

12-28-86

APPENDIX E
POWERPLANT WEIGHT STUDY

This report focuses on the weight penalty for each airplane as a result of the commonality requirements. The commality concept currently embraces the following:

25, 36, 50 Passenger Single Body Airplanes use 2-6000 shp engines

75, 100 Passenger Twin Body Airplanes use 2-13,500 shp engines.

Pages 2-6 show the powerplant weight breakdowns and the penalty for commonality. Page 12 is a summary.

It is obvious that we can minimize these weight penalties by replacing the 6,000 and 13,500 shp engines with 5,500 and 11,000 shp engines respectively. Pages 7-11 show the results. Page 12 provides a summary.

The following conclusions can be made:

1. It is essential that the required horsepower for the 50 and 100 passenger designs be pinned down.
2. The weight penalty for engine commanality can be expected to be as much as 4 percent of the airplane take-off weight (this is for the 25 passenger design -- the extreme).

25 Passenger Single Body

6,000 shp Concept

We:	879.39		
Wgb:	302.60		
Wn:	678.21	Wpwr:	5,956.10
Wprop:	845.00		
Wfs:	422.58		
Wosc:	123.11		

Data:	shp:	6,000.00	Ne:	2.00
	Nt:	2.00	WF:	3,767.00
	Kfsp:	5.87	GR:	8.99
	Kosc:	0.07	Dprop:	10.00
	Lnac:	16.24		

Optimized

We:	614.85		
Wgb:	177.86		
Wn:	678.21	Wpwr:	5,140.51
Wprop:	845.00		
Wfs:	422.58		
Wosc:	86.08		

Data: shp: 4,210.00

Difference in powerplant weights is: 815.59

36 Passenger Single Body

6,000 shp Concept

We:	879.39			
Wgb:	302.60			
Wn:	678.21		Wpwr:	5,982.12
Wprop:	845.00			
Wfs:	448.60			
Wosc:	123.11			

Data:	shp:	6,000.00	Ne:	2.00
	Nt:	2.00	WF:	5,620.00
	Kfsp:	5.87	GR:	8.99
	Kosc:	0.07	Dprop:	10.00
	Lnac:	16.24		

Optimized

We:	655.43			
Wgb:	195.56			
Wn:	678.21		Wpwr:	5,288.78
Wprop:	845.00			
Wfs:	448.60			
Wosc:	91.76			

Data: shp: 4,485.00

Difference in powerplant weights is: 693.34

50 Passenger Single Body

6,000 shp Concept

We:	879.39				
Wgb:	302.60				
Wn:	678.21		Wpwr:	5,997.29	
Wprop:	845.00				
Wfs:	463.77				
Wosc:	123.11				

Data:	shp:	6,000.00	Ne:	2.00
	Nt:	2.00	WF:	6,939.00
	Kfsp:	5.87	GR:	8.99
	Kosc:	0.07	Dprop:	10.00
	Lnac:	16.24		

Optimized

We:	805.40		
Wgb:	265.58		
Wn:	678.21	Wpwr:	5,764.91
Wprop:	845.00		
Wfs:	463.77		
Wosc:	112.76		

Data: shp: 5,500.00

Difference in powerplant weights is: 232.38

75 Passenger Twin Body

13,500 shp Concept

We:	1,994.73				
Wgb:	1,021.28				
Wn:	678.21		Wpwr:	9,999.53	
Wprop:	845.00				
Wfs:	641.81				
Wosc:	279.26				

Data:	shp:	13,500.00	Ne:	2.00
	Nt:	3.00	WF:	11,240.00
	Kfsp:	5.87	GR:	8.99
	Kosc:	0.07	Dprop:	10.00
	Lnac:	16.24		

Optimized

We:	1,324.44		
Wgb:	555.92		
Wn:	678.21	Wpwr:	7,634.37
Wprop:	845.00		
Wfs:	641.81		
Wosc:	185.42		

Data: shp: 9,000.00

Difference in powerplant weights is: 2,365.16

100 Passenger Twin Body

13,500 shp Concept

We:	1,994.73		
Wgb:	1,021.28		
Wn:	678.21	Wpwr:	10,022.93
Wprop:	845.00		
Wfs:	665.22		
Wosc:	279.26		

Data:	shp:	13,500.00	Ne:	2.00
	Nt:	3.00	WF:	13,878.00
	Kfsp:	5.87	GR:	8.99
	Kosc:	0.07	Dprop:	10.00
	Lnac:	16.24		

Optimized

We:	1,622.01		
Wgb:	751.16		
Wn:	678.21	Wpwr:	8,685.07
Wprop:	845.00		
Wfs:	665.22		
Wosc:	227.08		

Data: shp: 11,000.00

Difference in powerplant weights is: 1,337.86

25 Passenger Single Body

5,500 shp Concept

We:	805.40		
Wgb:	265.58		
Wn:	678.21	Wpwr:	5,723.73
Wprop:	845.00		
Wfs:	422.58		
Wosc:	112.76		

Data:	shp:	5,500.00	Ne:	2.00
	Nt:	2.00	WF:	3,767.00
	Kfsp:	5.87	GR:	8.99
	Kosc:	0.07	Dprop:	10.00
	Lnac:	16.24		

Optimized

We:	614.85		
Wgb:	177.86		
Wn:	678.21	Wpwr:	5,140.51
Wprop:	845.00		
Wfs:	422.58		
Wosc:	86.08		

Data:	shp:	4,210.00

Difference in powerplant weights is: 583.22

36 Passenger Single Body

5,500 shp Concept

We:	805.40				
Wgb:	265.58				
Wn:	678.21		Wpwr:	5,749.74	
Wprop:	845.00				
Wfs:	448.60				
Wosc:	112.76				

Data:	shp:	5,500.00	Ne:	2.00
	Nt:	2.00	WF:	5,620.00
	Kfsp:	5.87	GR:	8.99
	Kosc:	0.07	Dprop:	10.00
	Lnac:	16.24		

Optimized

We:	655.43		
Wgb:	195.56		
Wn:	678.21	Wpwr:	5,288.78
Wprop:	845.00		
Wfs:	448.60		
Wosc:	91.76		

Data:	shp:	4,485.00

Difference in powerplant weights is: 460.96

50 Passenger Single Body

5,500 shp Concept

We:	805.40				
Wgb:	265.58				
Wn:	678.21		Wpwr:	5,764.91	
Wprop:	845.00				
Wfs:	463.77				
Wosc:	112.76				

Data:	shp:	5,500.00	Ne:	2.00
	Nt:	2.00	WF:	6,939.00
	Kfsp:	5.87	GR:	8.99
	Kosc:	0.07	Dprop:	10.00
	Lnac:	16.24		

Optimized

We:	805.40			
Wgb:	265.58			
Wn:	678.21		Wpwr:	5,764.91
Wprop:	845.00			
Wfs:	463.77			
Wosc:	112.76			

Data:	shp:	5,500.00

Difference in powerplant weights is: 0.00

75 Passenger Twin Body

11,000 shp Concept

We:	1,622.01				
Wgb:	751.16				
Wn:	678.21		Wpwr:	8,661.67	
Wprop:	845.00				
Wfs:	641.81				
Wosc:	227.08				

Data:	shp:	11,000.00	Ne:	2.00
	Nt:	3.00	WF:	11,240.00
	Kfsp:	5.87	GR:	8.99
	Kosc:	0.07	Dprop:	10.00
	Lnac:	16.24		

Optimized

We:	1,324.44		
Wgb:	555.92		
Wn:	678.21	Wpwr:	7,634.37
Wprop:	845.00		
Wfs:	641.81		
Wosc:	185.42		

Data: shp: 9,000.00

Difference in powerplant weights is: 1,027.30

100 Passenger Twin Body

11,000 shp Concept

We:	1,622.01				
Wgb:	751.16				
Wn:	678.21		Wpwr:	8,685.07	
Wprop:	845.00				
Wfs:	665.22				
Wosc:	227.08				

Data:	shp:	11,000.00	Ne:	2.00
	Nt:	3.00	WF:	13,878.00
	Kfsp:	5.87	GR:	8.99
	Kosc:	0.07	Dprop:	10.00
	Lnac:	16.24		

Optimized

We:	1,622.01		
Wgb:	751.16		
Wn:	678.21	Wpwr:	8,685.07
Wprop:	845.00		
Wfs:	665.22		
Wosc:	227.08		

Data: shp: 11,000.00

Difference in powerplant weights is: 0.00

Class II Powerplant Commonality Analysis

Airplane:	WTO: lbs	Commonality Penalty: lbs	% of WTO:
6,000 shp concept			
25 Pass	21,046.00	815.59	3.88
36 Pass	31,395.00	693.34	2.21
50 Pass	42,057.00	232.38	0.55
13,500 shp concept			
75 Pass - Twin	60,683.00	2,365.16	3.90
100 Pass - Twin	80,716.00	1,337.86	1.66

Class II Powerplant Commonality Analysis

Airplane:	WTO: lbs	Commonality Penalty: lbs	% of WTO:
5,500 shp concept			
25 Pass	21,046.00	583.22	2.77
36 Pass	31,395.00	460.96	1.47
50 Pass	42,057.00	0.00	0.00
11,000 shp concept			
75 Pass - Twin	60,683.00	1,027.30	1.69
100 Pass - Twin	80,716.00	0.00	0.00