CLASS II DESIGN UPDATE
FOR THE FAMILY OF COMMUTER AIRPLANES

PREPARED FOR: NASA GRANT NGT-8001

PREPARED BY: THOMAS R. CREIGHTON
LOUIS J. HENDRICH

UNIVERSITY OF KANSAS
AE 790 DESIGN TEAM
MAY 1987

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TEAM MEMBERS: RAPHAEL HADDAD
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FACULTY ADVISOR: DR. JAN ROSKAM

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List 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_{D_o}	Zero lift drag coefficient	-----
c_l	Section lift coefficient	-----
c_{l_α}	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	ft2
FAR	Federal Air Regulation	-----
g	Acceleration of gravity	ft/sec2
h	Altitude	ft
i_w	Wing incidence angle	degrees
k_Δ	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

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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/ft2
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	ft2
SHP	Shaft horsepower	hp
S_{wet}	Wetted area	ft2
S_{wf}	Flapped wing area	ft2
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

Greek Symbols

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 the final report of seven design reports completed on the family of commuter airplanes. This design effort is completed in fulfillment of NASA/USRA grant NGT-8001.

Reference 1 contains the class I baseline designs for the commuter family. Reference 2 contains a study of take-off weight penalties imposed on the commuter family due to implementing commonality objectives. Reference 3 contains component structural designs that are common to the commuter family. Reference 4 details the acquisition and operating economics of the commuter family. The savings due to production commonality and handling qualities commonality are determined. Reference 5 details the selection of an advanced turboprop propulsion system for the family of commuter airplanes. Reference 6 contains a proposed design for a SSSA controller design to achieve similar handling for all airplanes.

The purpose of this report is to present the final class II commuter airplane designs.

Chapter 2 presents the class II threeviews and includes a review of the extent commonality is integrated into the family.

Chapter 3 details the mass properties of the family of commuter airplanes.

Chapter 4 details the stability and open loop handling characteristics of the family.

Chapter 5 presents the stick forces and gradients for the airplanes.

Chapter 6 presents class II drag polars for the family.

Chapter 7 discusses the mission performance and determines if all mission requirements are met.

Chapter 8 summarizes weight penalties and cost savings due to implementation of commonality.

Chapter 9 compares the commuter family to existing airplanes.

Chapter 10 concludes this report with a discussion of commonality objectives and the extent of implementation of these objectives.

The family concept is introduced in order to achieve structural, systems, and handling qualities commonality throughout the passenger range. Implementing commonality can substantially reduce manufacturing and production costs. By achieving common system designs maintenance costs can be reduced by allowing airlines to keep a smaller inventory of spare parts. Therefore, the higher degree of commonality that can be achieved will result in lower direct operating costs and lower life cycle cost.

The design of commonality into a family concept must occur at the very early stages of the design process. Otherwise achieving a high degree of commonality throughout a wide range of passenger capability will be impossible.

Attempting to implement many of these commonality requirements has caused configuration design problems. The twin body concept is introduced in an effort to retain commonality throughout the passenger range.

The proposed commuters range from 25 to 100 passengers. Figure 1.1 displays the family concept. All the airplanes in the family will incorporate the following common characteristics:

1) Advanced technology turboprop engines
2) NLF surfaces
3) Common cockpit instrumentation
4) Common structural and systems designs (to at high a degree as possible)
5) Jet-like ride and cabin environment
6) Identical handling qualities allowing for cross rating of pilots
7) Low acquisition cost and low life-cycle cost

The following configuration decisions were incorporated into the family of commuter airplanes:

1) Low Wing
2) 2 Aft-Fuselage Mounted Engines
3) T-Tail Empennage
4) Tricycyle Landing Gear
5) Twin Body Configurations

The following advanced technologies were integrated into the family of commuter airplanes:

1) NLF Surfaces
2) Advanced Technology Turboprops
3) SSSA Technology

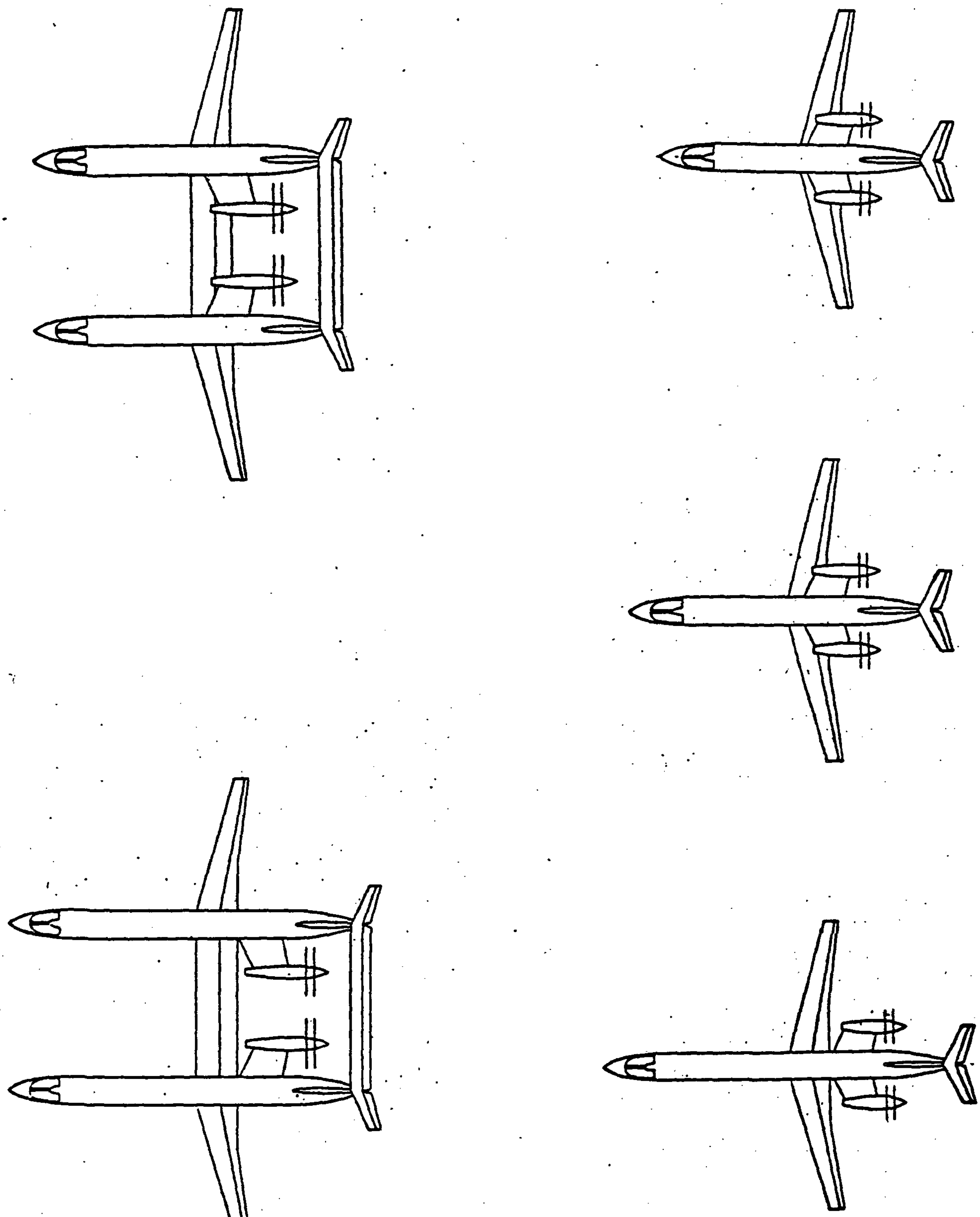

Figure 1.1 The Family Concept

2. Configuration Descriptions

The purpose of this chapter is to present the class II configuration designs for the family of commuter airplanes. The common design features that are incorporated into the family are listed in Table 2.1. The mission specifications for which the commuter family has been designed are given in Table 2.2

Table 2.1 - Common Features Desired in the Advanced Technology Commuter Family

Feature	Implementation
Fuselage cross section	Completed
Common landing gear Tires, struts, shocks and brakes (Both nose and main gear)	Completed
Common NLF airfoil	Completed
Common wing ($S=592\ ft^2$, $A=12$)	Completed*
Common empennage ($S_H=120\ ft^2$, $S_V=170\ ft^2$)	Completed**
Common powerplants	Completed***
Common tailcone/engine arrangement	Completed
Common cockpit instrumentation	Completed
Common flight systems	Completed
Flight control	SSSA
Fuel	in wing
Pressurization	behind cabin
De-icing and bug removal	TKS

*The twinbody airplanes require a wing centerpiece of 590 ft^2

**The twinbody airplanes require a horizontal tail bar of 290 ft^2

***Two powerplants were selected. A 5500 shp engine, and a 11000 shp engine for the 75 and 100 passenger models.

Table 2.2 - Mission Specification for the Commuter Family

	25 pax	36 pax	50 pax	75 pax	100 pax
Crew	2	3	3	4	4
Range (n.m.)	1100	1100	1100	1500	1500
Altitude	All Cruise at 30,000 ft.				
Cruise Speed	All Cruise at Mach 0.70				
Climb	All Climb-out at 3,000 fpm				
TOFL, LFL	All Field Lengths are 3,500 ft				
Powerplants (shp)	5500	5500	5500	11000	11000
Pressurization	All Pressurized 5,000 ft at 30,000 ft				
Certification	All FAR 25				

2.1 Review of Common Design Features

This section is intended to review the commonality objectives of Reference 1. and summarize how these commonality goals were achieved.

2.1.1 Common Structural Component Features

The following components are common to every airplane in the family:

1) Fuselage Cross Section (see Figure 2.1)
2) Flight Deck Layout (see Figure 2.2)
3) Powerplants (see Figures 2.3 and 2.4)
4) Powerplane integration (see Figures 2.5 and 2.6)
5) Airfoil Cross Section (see Figure 2.7)
6) Wing Layouts (see Figures 2.8 and 2.9)
7) Main Gear Installation (see Figure 2.10)
8) Tailcone Arrangements (see Figure 2.11 and 2.12)

The twin body airplanes required some additional structure. This is pointed out in Table 2.1. The example production and manufacturing breakdowns contained in Figures 2.13 and 2.14, show this necessary structure more clearly.

Chapters 2 and 5 of Reference 1. define the commonality objectives and discuss the reasons for arriving at the common component designs in Figures 2.1 to 2.14.

A more detailed discussion of structural designs and structural commonality is contained in Reference 3.

Detailed information about the powerplants can be found in Reference 5.

The weight penalties imposed by commonality are the subject of Reference 2. These weight penalties are summarized in Chapter 8.

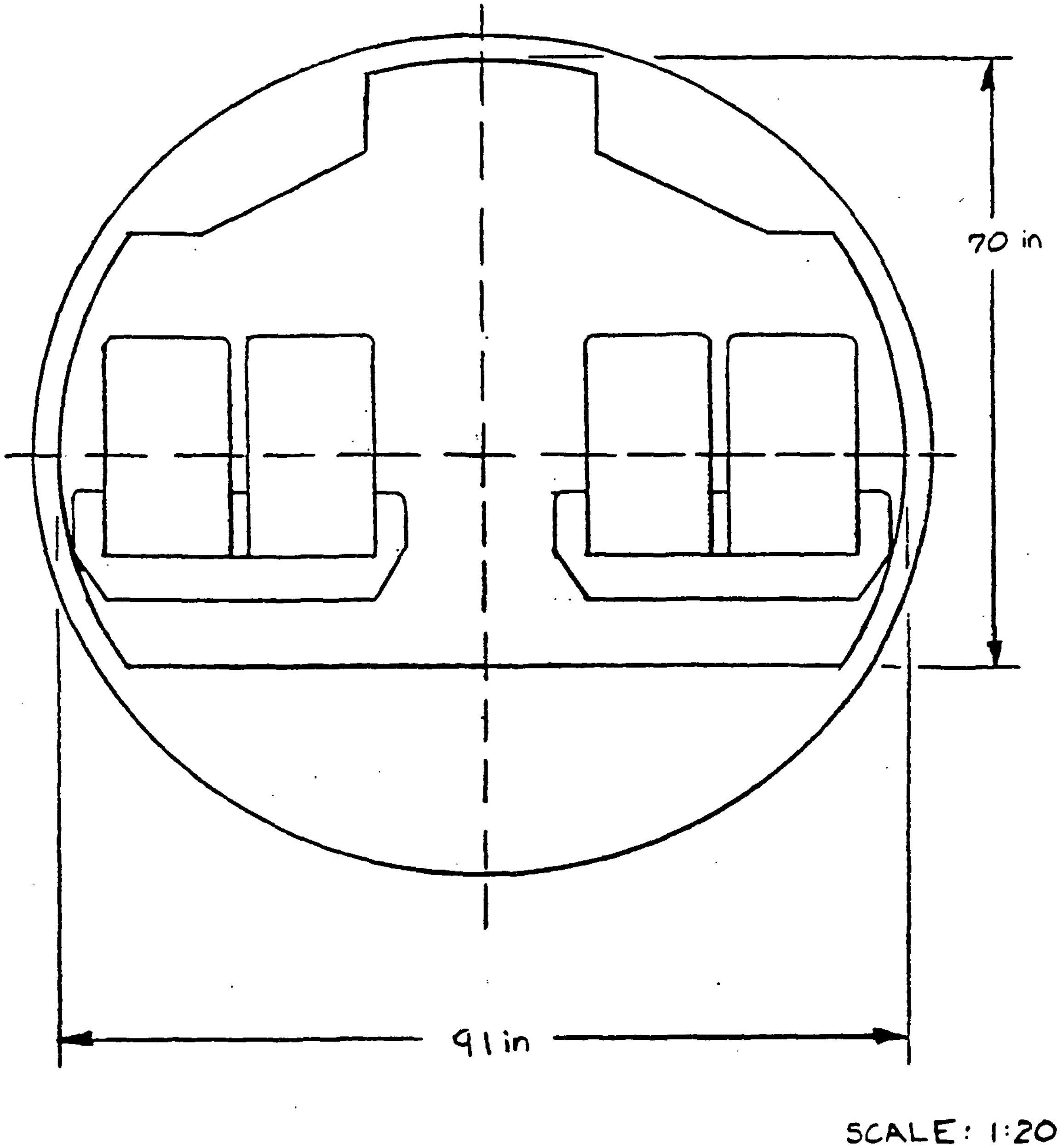

FIGURE 2.1 FUSELAGE CROSS SECTION

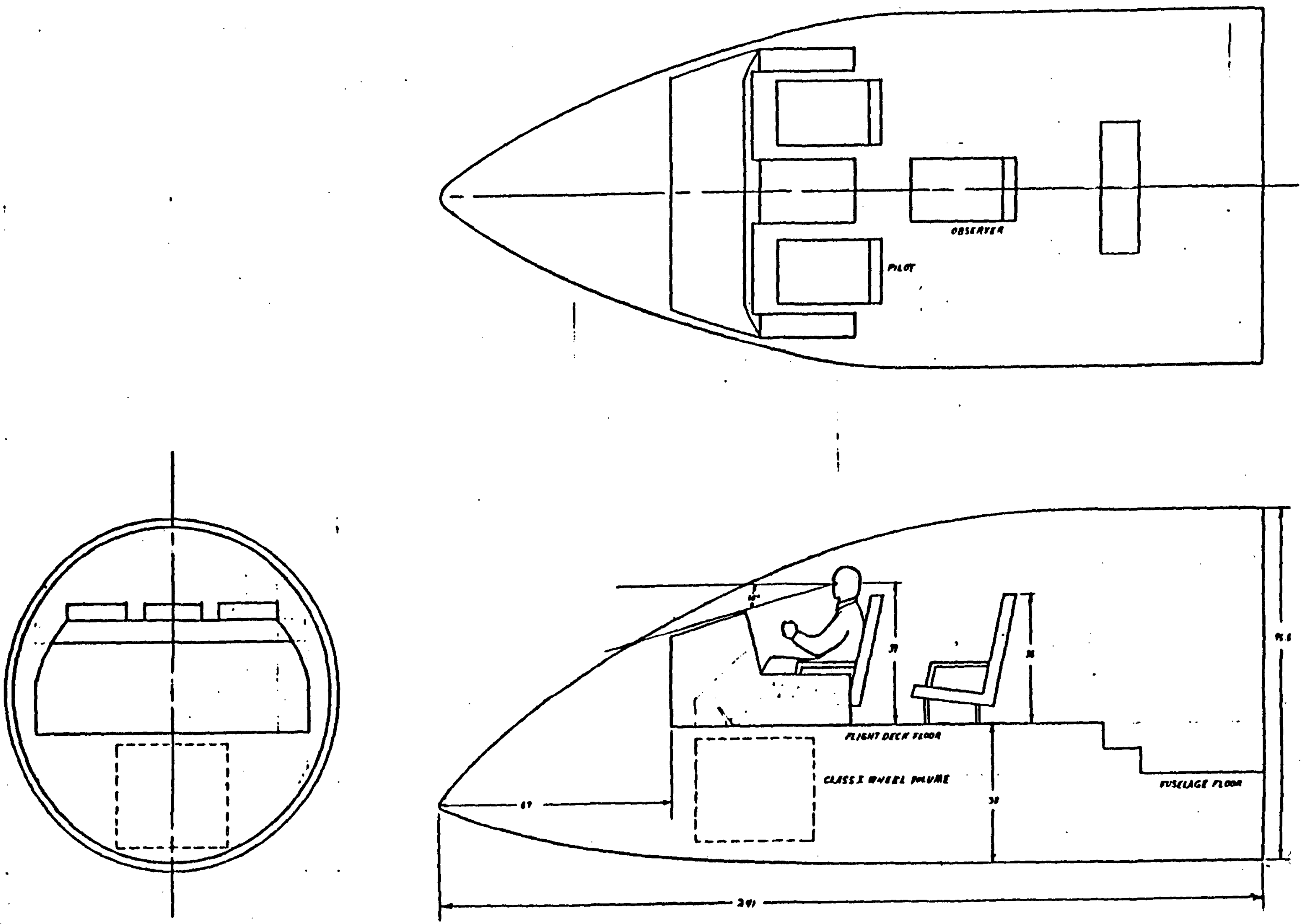

FIGURE 2.2 FLIGHT DECK LAYOUT

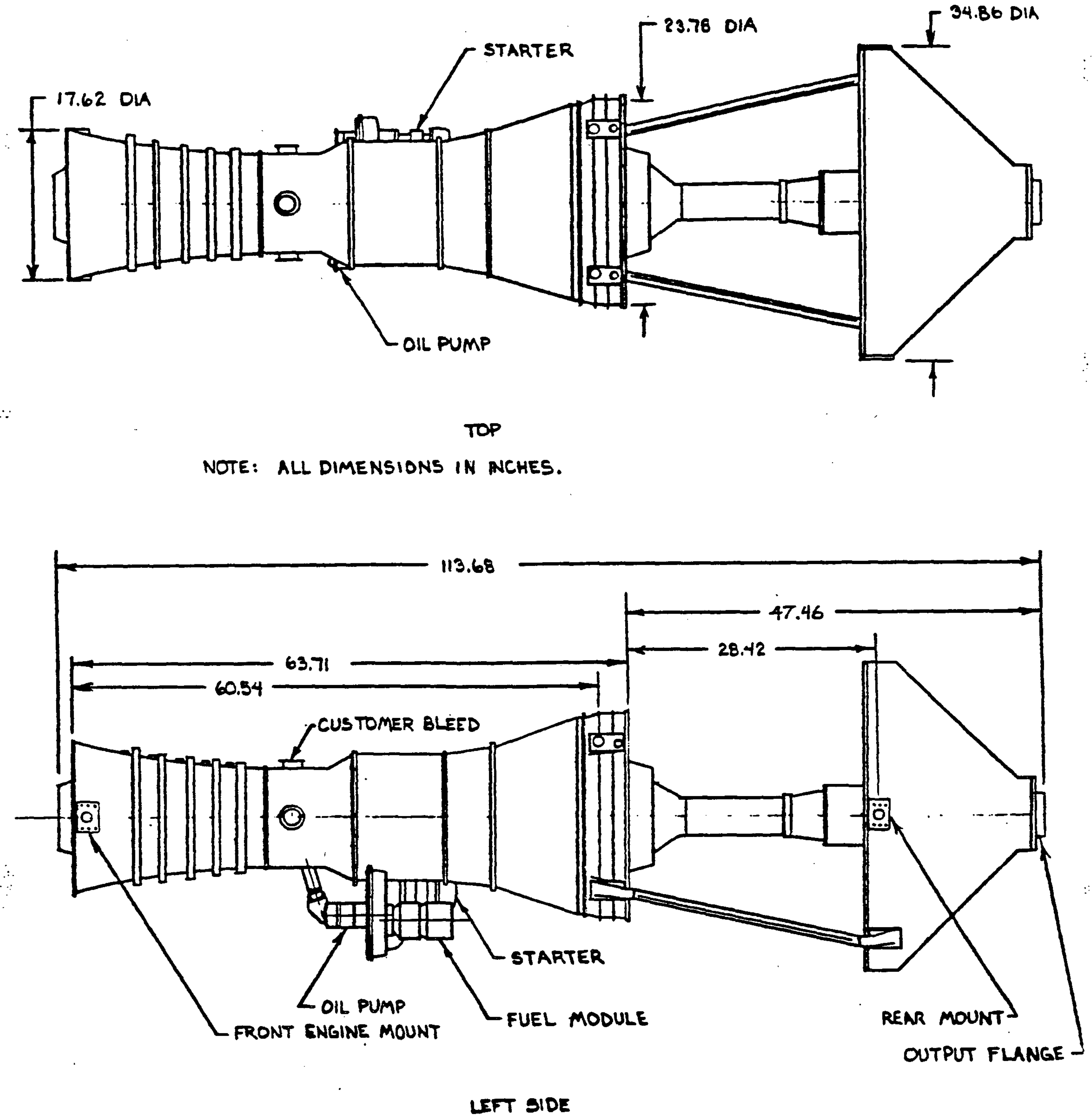

Figure 2.3 5500 SHP PD436-11 Derivative Outline Drawing

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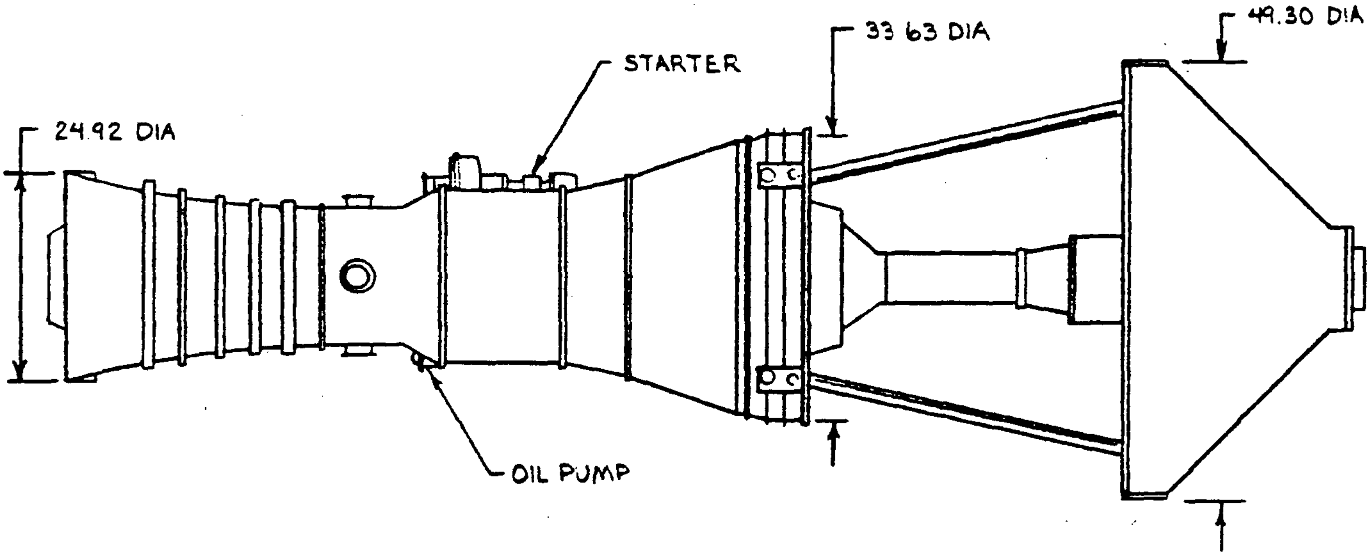
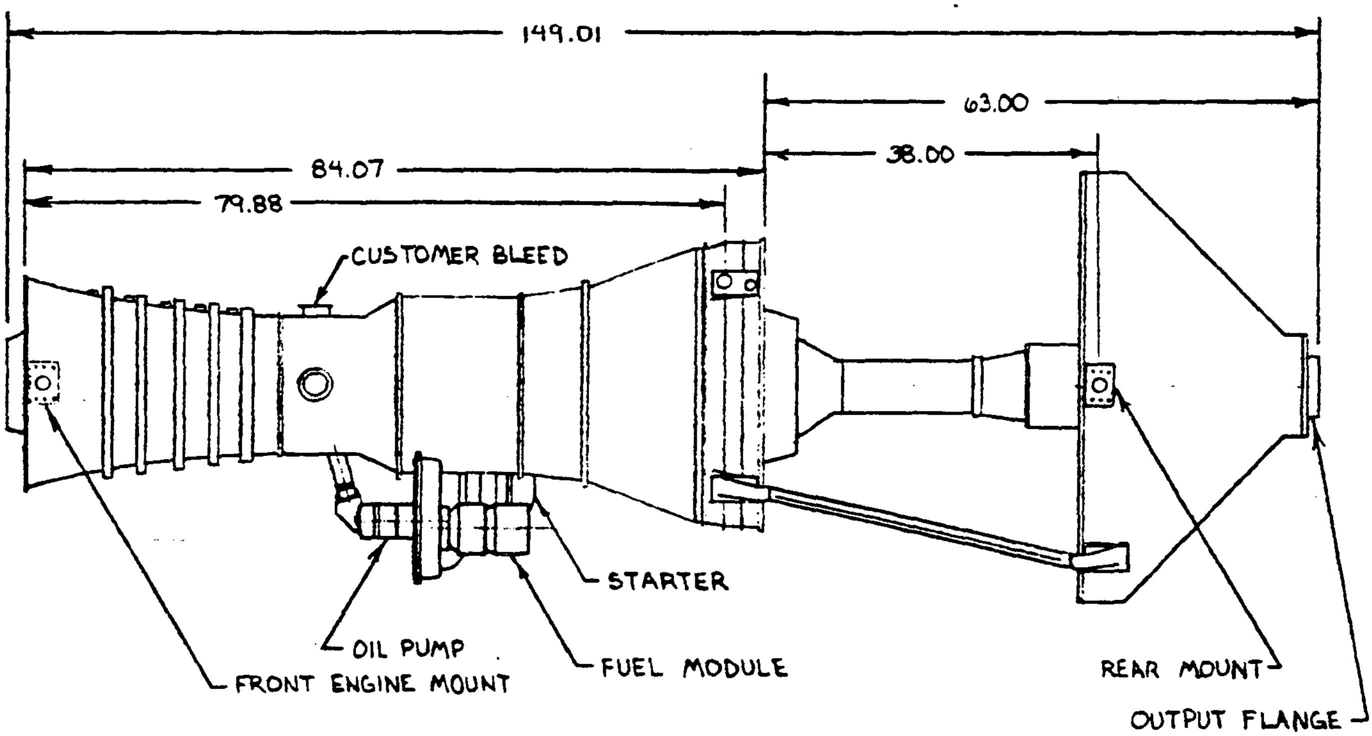


TOP



LEFT SIDE

Figure 2.4 11000 SHP PD436-11 Derivative Outline Drawing

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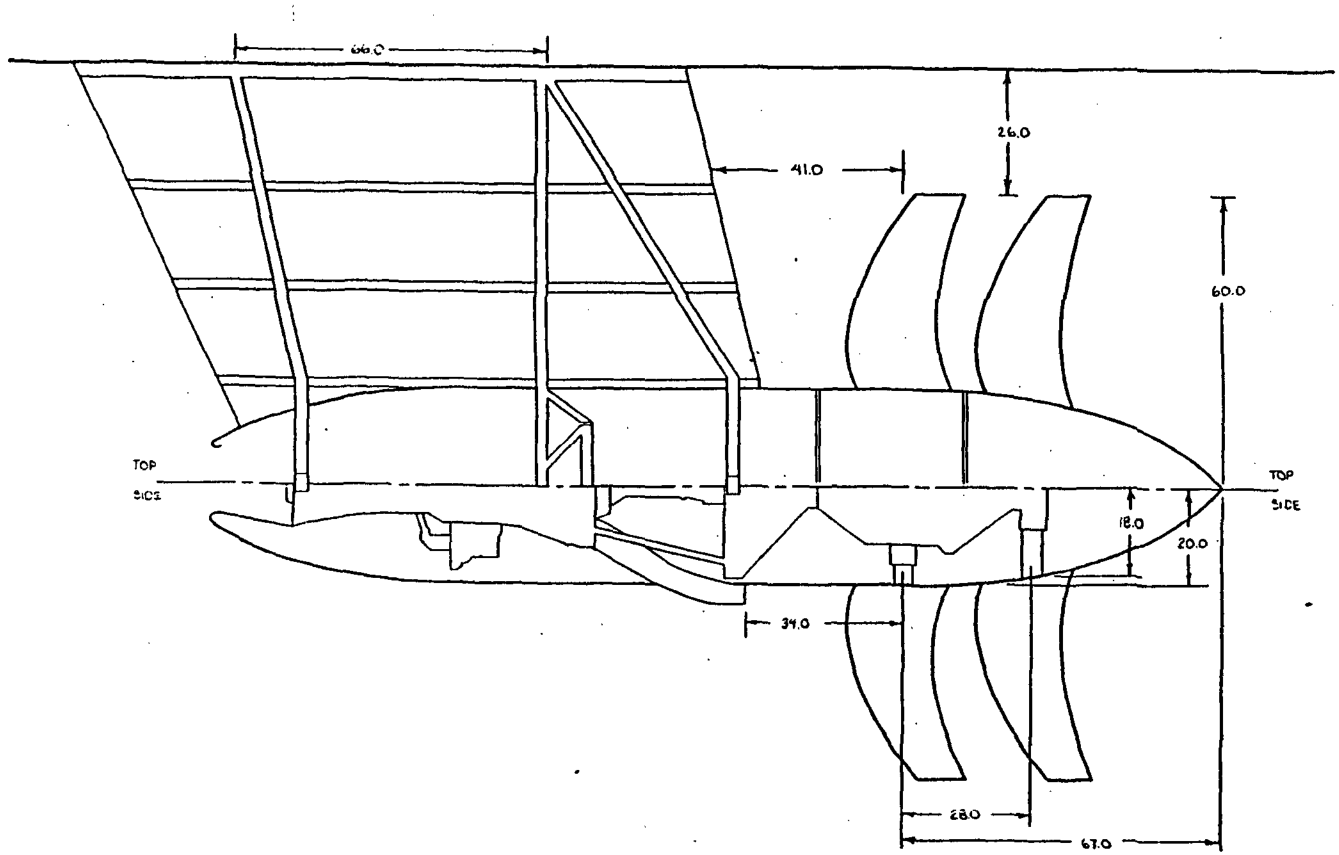


Figure 2.5 5500 SHP Powerplant Integration

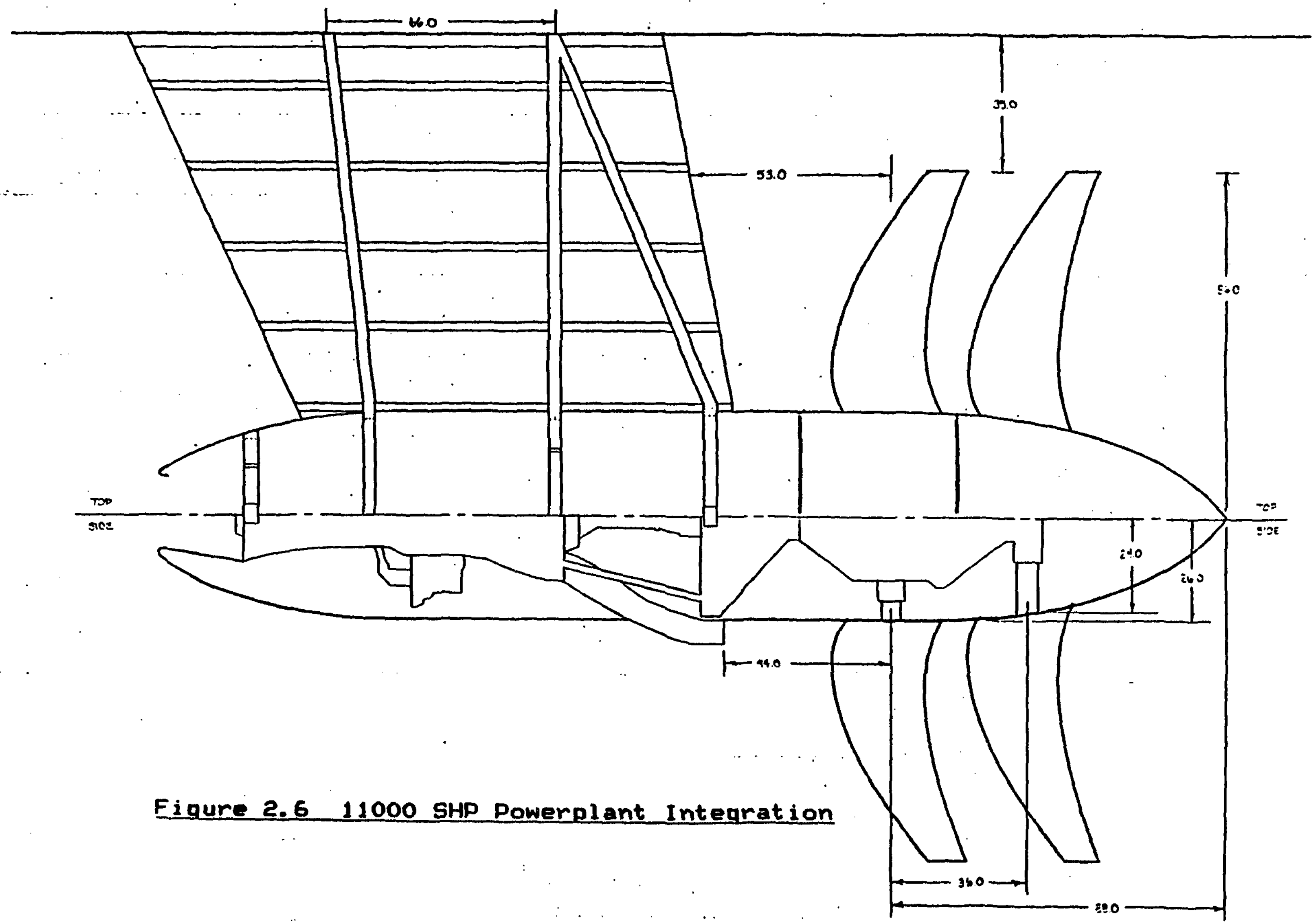


Figure 2.6 11000 SHP Powerplant Integration

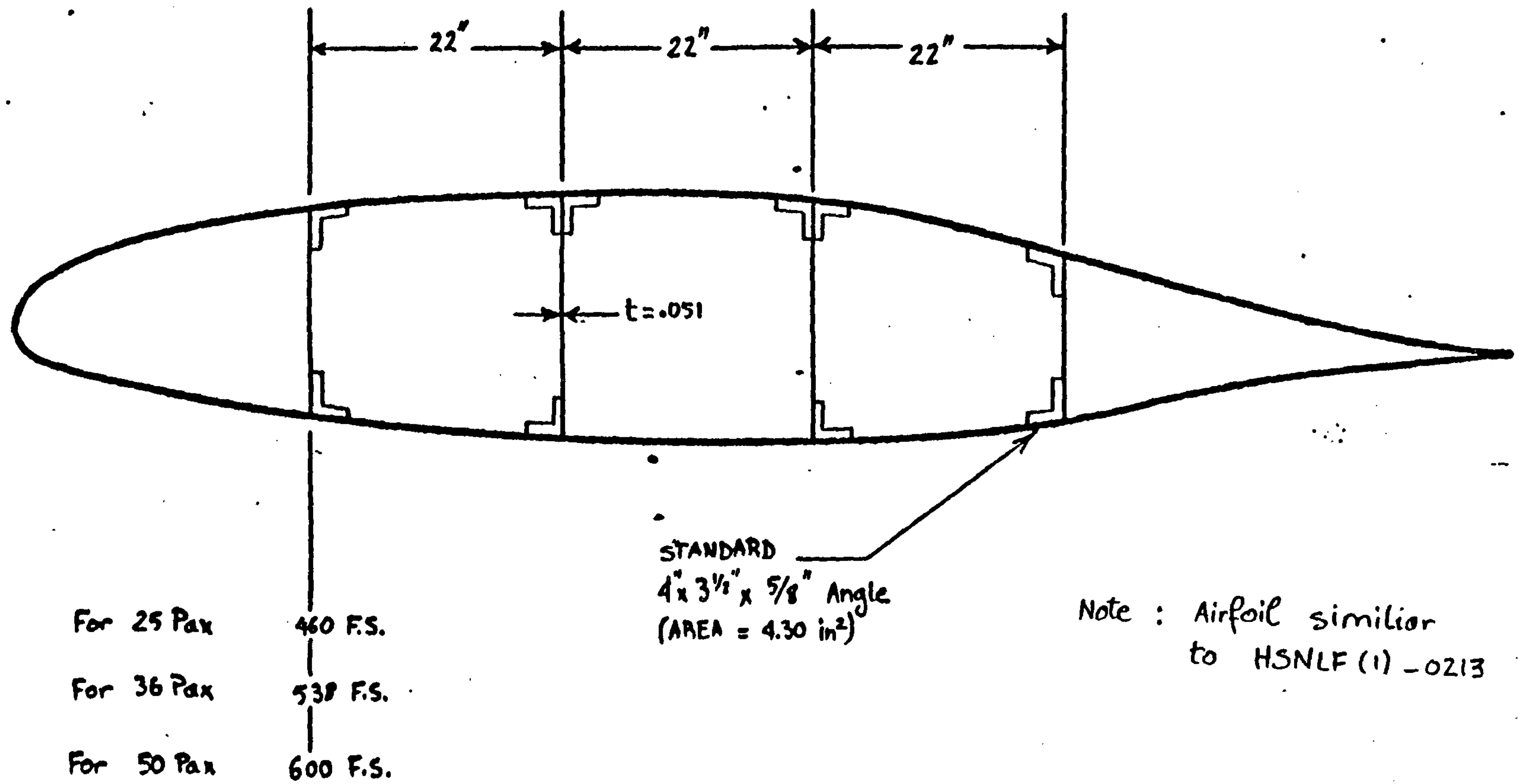
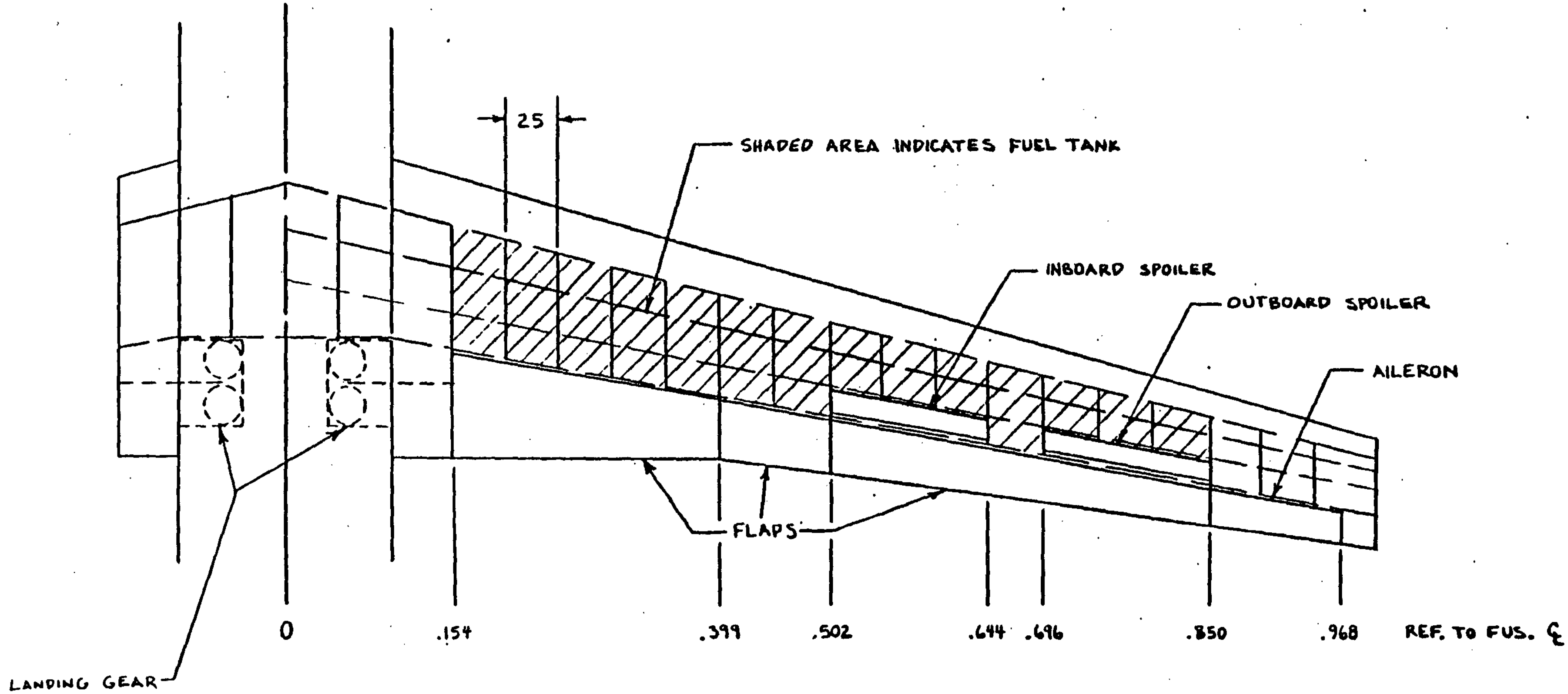


Figure 2.7 Wing Cross Section



Wing Geometry

$S = 592\ ft^2$
$b = 84.3\ ft$
$A = 12$

$\bar{c} = 7.45$

$t/c = .13$
$\lambda = .40$
$\Lambda_{LE} = 16\ deg$

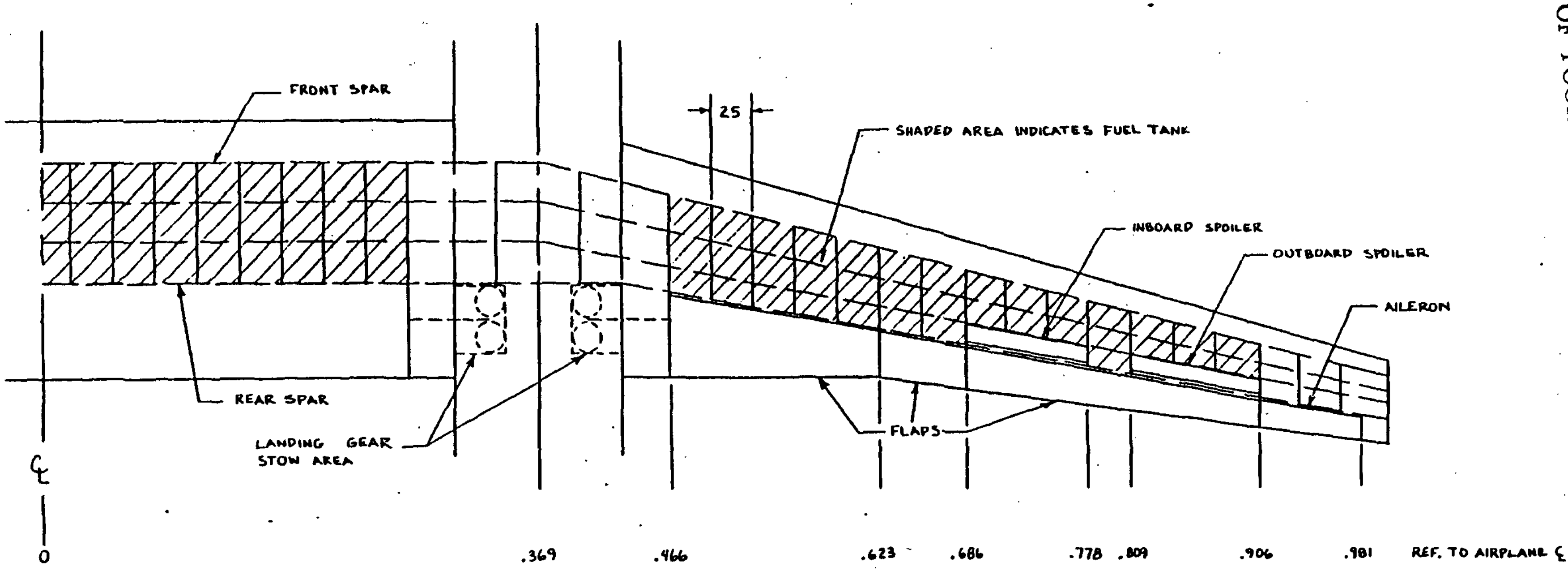
$c_f/c = .30$

$S_a = 6.25\ ft^2$
$S_{sp} = 7.67\ ft^2$
$c_{sp}/c = .10$

$R_{N_{CR}} = 20 \times 10^6$ (root chord)

$R_{N_{CR}} = 8 \times 10^6$ (tip chord)

Figure 2.8 Wing Layout

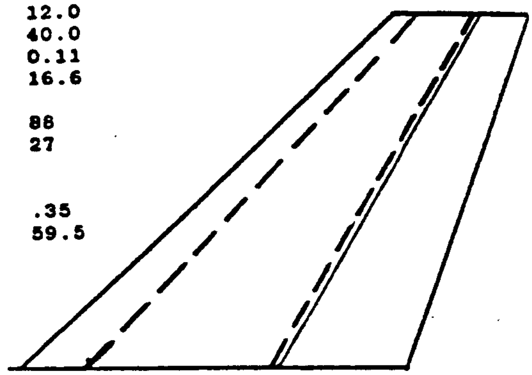


Centerpiece Wing Area = 590 ft^2

Figure 2.9 Twin-body Wing Layout

Geometry of the Empennage

	H-Tail	V-Tail
Area, ft^2	120	170
Span, ft	26.6	15.4
Aspect Ratio	5.88	1.4
Taper Ratio	0.50	0.33
M.G.C., ft	4.68	12.0
L.E. Sweep, deg	20.0	40.0
Thickness Ratio	0.11	0.11
Root Chord, ft	6.02	16.6
Spar Box Length:		
root, in	27	88
tip, in	13	27
Elevator Chord Ratio	.35	
Elevator Area, ft^2	42.0	
Rudder Chord Ratio		.35
Rudder Area, ft^2		59.5



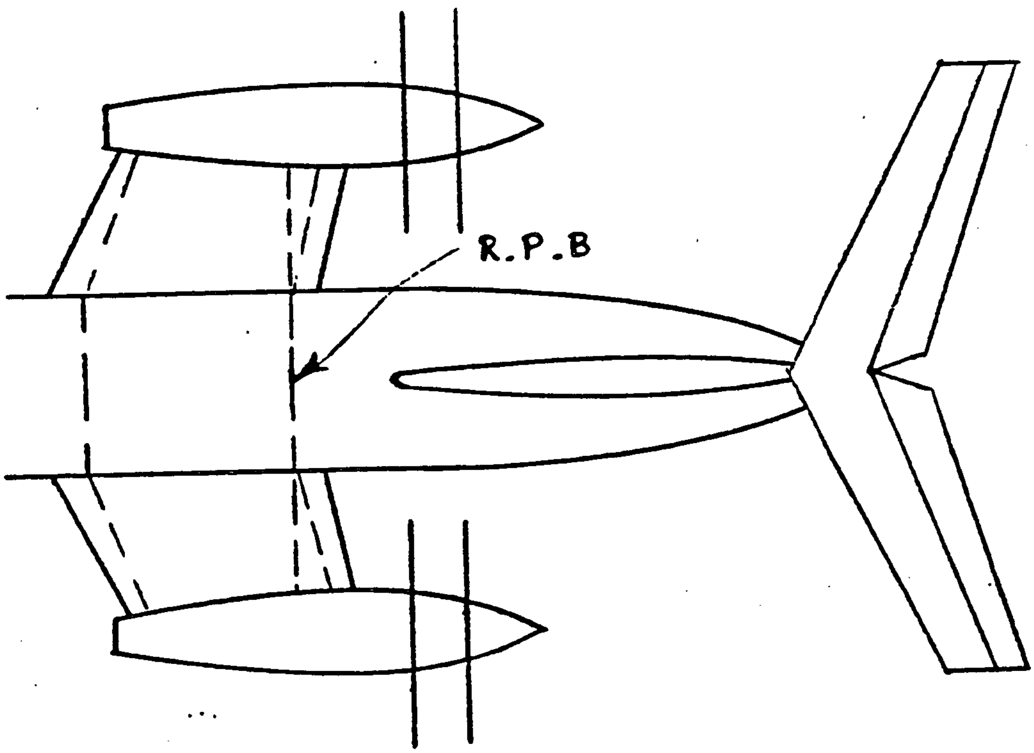


Figure 2.11

Common Tailcone-Engine Integration for the 25, 36, and 50 Pax Models

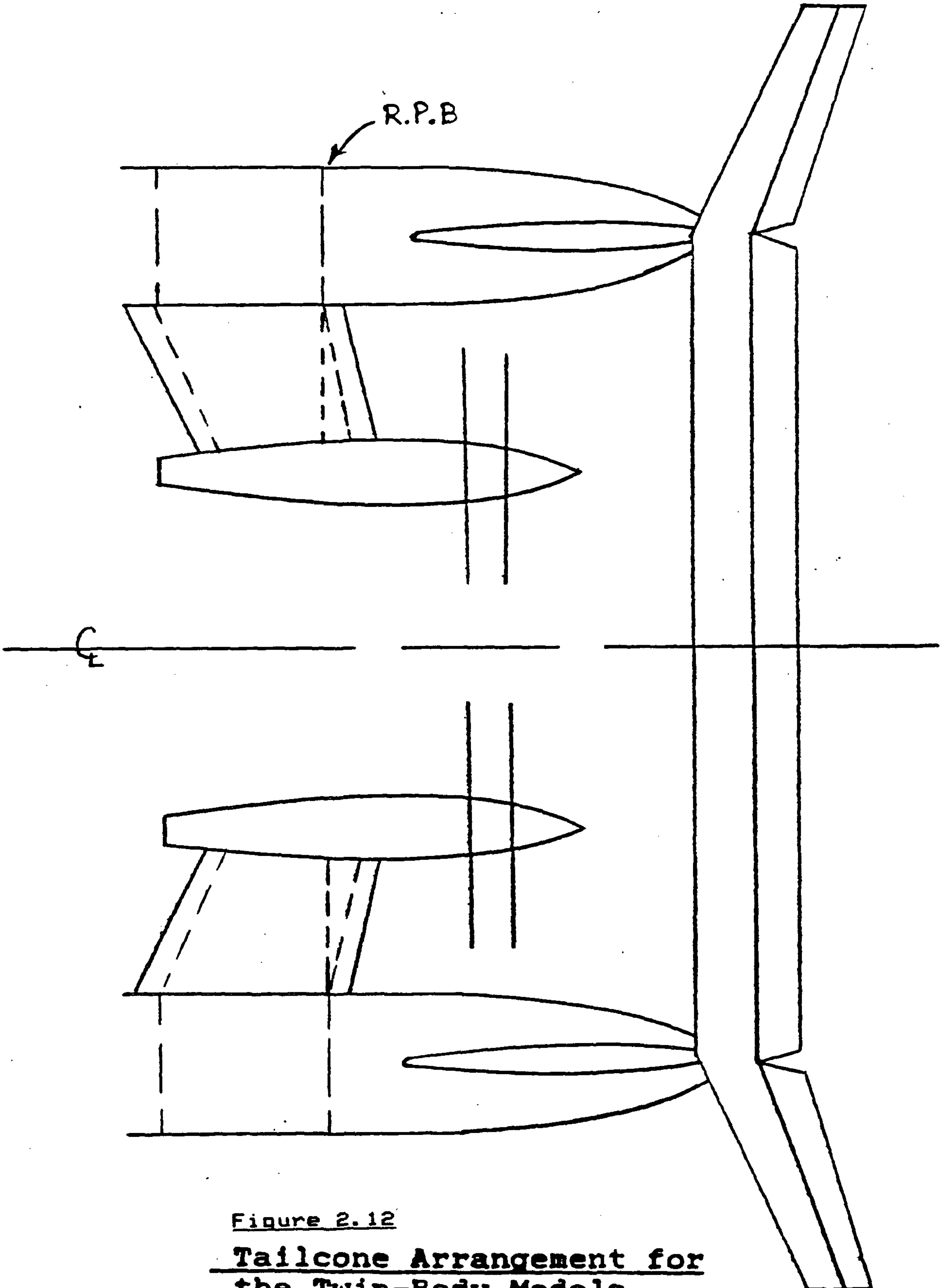


Figure 2.12

Tailcone Arrangement for the Twin-Body Models

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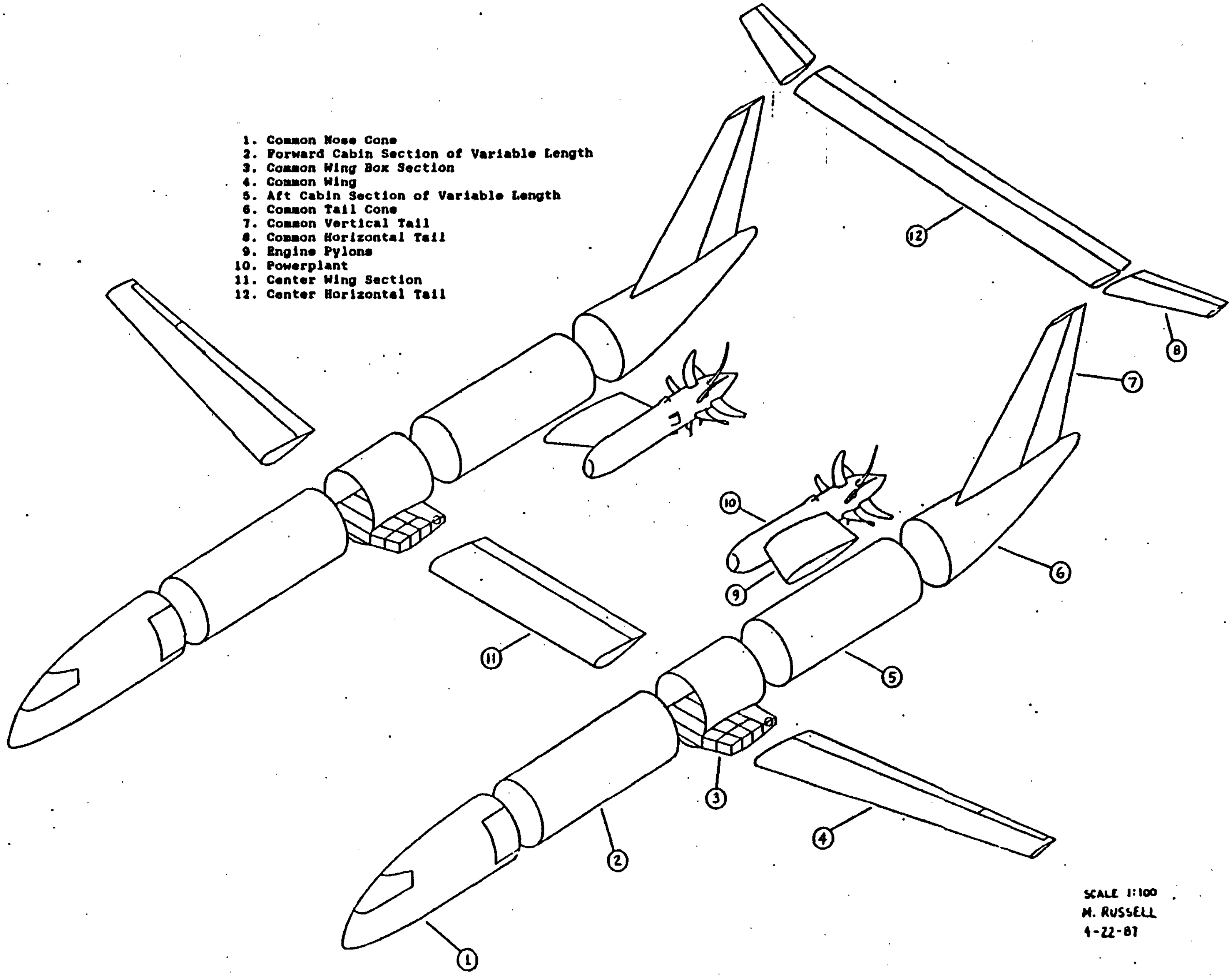

Figure 2.14 Production and Manufacturing Breakdown Example

2.1.2 Common Flight System Designs

The purpose of this section is to present the systems that are common to every airplane in the commuter family. After the Class II configurations are presented, an analysis of the extent in which commonality was integrated will be detailed. This is accomplished in Chapter 8.

Commonality of airplanes in the family is an effort to substantially lower acquistion and operating costs for the airplanes. In turn, the airlines will have a wide range of passenger capacity airplanes to operate. A high degree of structural and systems commonality will also result in a smaller spare parts inventory for the airline.

2.1.2.1 Interior Layouts

All airplanes in the family have a 4-abreast seating arrangement. The fuselage cross section is presented in Figure 2.1. The rationale for arriving at this decision is given in Appendix A.

A preliminary flight deck layout is shown in Figure 2.2. Appendix A describes the flight deck layout and provides a list of cockpit instruments. In the interest of instrument commonality, it was decided that all members of the family have two engines. Therefore, there are two throttles in each cockpit.

2.1.2.2 Landing Gear System

All landing gear, nose and main, have the same 18" x 9" tire. The main gear wheel base (15ft on the single body models, 63.2ft on the twin-body models) and retraction scheme is the same. This allows for similar strut sizing for the airplanes. Figure 2.10 provides the dimensions of each gear strut.

2.1.2.3 Fuel System

All airplanes in the commuter family carry fuel in the wing. Since a common wing torque box arrangement is proposed, the integral fuel tanks will be the same on all airplanes. Similar vents, pumps and access panels will be incorporated into all members of the family.

2.1.2.4 Flight Control System

A reversible flight control system is designed for the family of commuter airplanes. Due to the aft pressure loading of the NLF airfoil, the aileron control system will be designed using push rods, instead of cables. This will prevent aileron up-float.

A separate surface stability augmentation system is proposed to achieve identical handling qualities throughout the passenger range. This system will make use of electro-hydrostatic actuation. Figure 2.15 shows a proposed SSSA system that could be incorporated into the commuters. Reference 6 contains a detailed SSSA control system design for the family of commuter airplanes.

2.1.2.5 Hydraulic System

A common operating pressure hydraulic system will be implemented for the landing gear actuation. Further study is neccesary to determine the operating capabilities of this system.

2.1.2.6 Pressurization System

All passenger cabins in the family are pressurized to a 5000 ft. atmosphere at 30,000 ft. All airplanes will utilize the same pressurization system.

2.1.2.7 De-Icing System

The T.K.S. de-icing system, which will also double as a bug-cleaner, will be implemented into the commuter family. The T.K.S. system is a liquid ice protection system that distributes a solution onto the leading edge of the wing through a porous wing skin. Cleaning the leading edge is required to preserve the laminar flow over the wing. Reference 7 detailes the capabilities of the T.K.S. system.

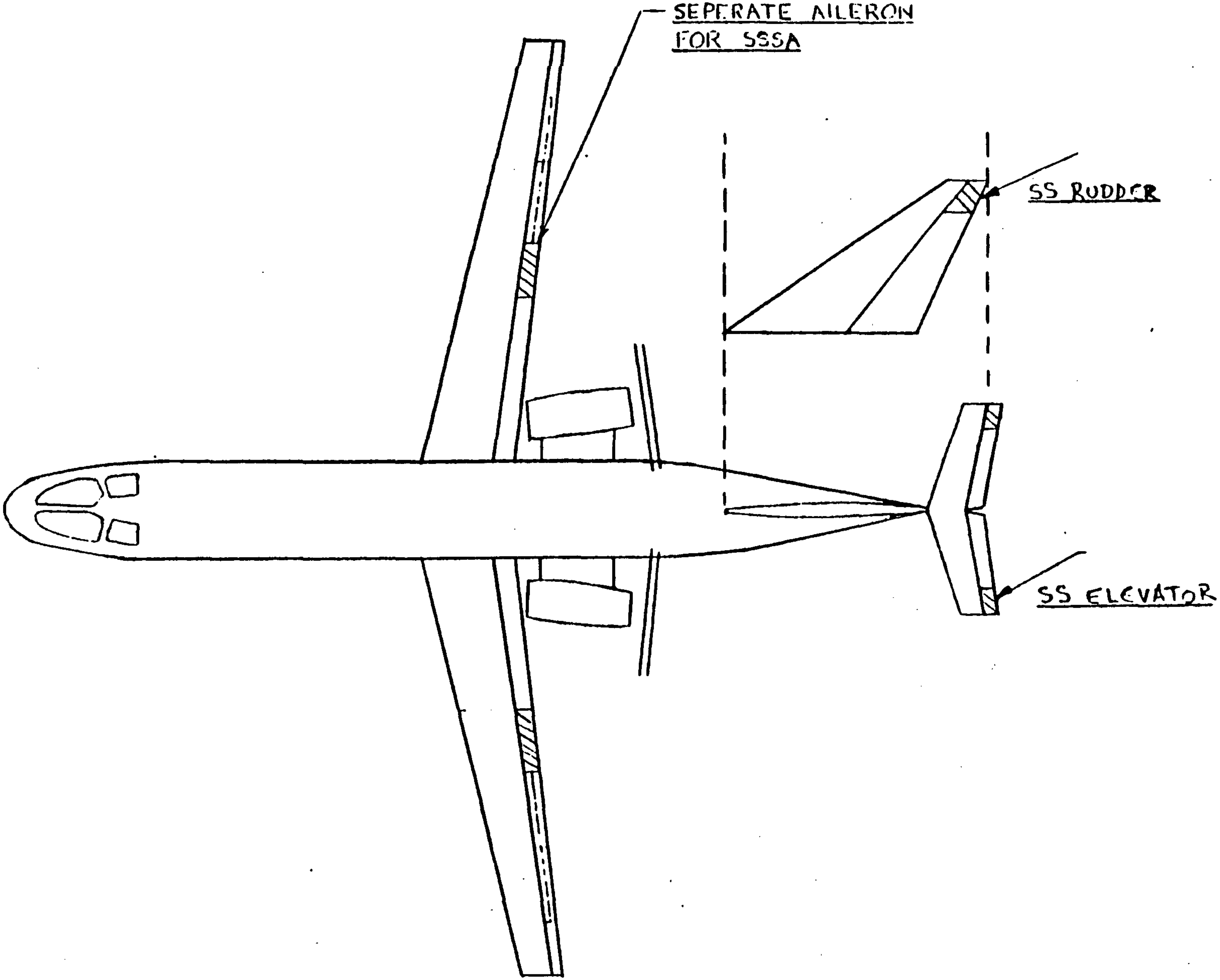

FIGURE 2.15 EXAMPLE OF A PROPOSED SSSA FLIGHT CONTROL SYSTEM

2.2 Presentation of Class II Threeviews

The commuter family threeviews are presented in Figures 2.16 to 2.20. Geometries of these configurations are given in Tables 2.3 to 2.8.

The twinbody concept is introduced in an effort to retain as much commonality throughout the passenger range as possible. Conventionally configured 75 and 100 passenger models are shown in Figures 2.21 and 2.22. The purpose of these figures is to show the impracticability of these concepts in terms of retaining commonality. The wing, tail surfaces, engines and take-off weight are all larger than the corresponding twin body concepts. Implementing many of the common structural designs was not possible with these configurations.

The wheel track of the twin fuselage models is 63.2 ft. From Airport Engineering by Ashford and Wright, the data of Appendix I is compiled. Conclusions drawn from this data on taxiway dimensions are:

1) The twinbody configuration can operate out of any commercial airline airport.

2) The twinbody configurations will not be able to operate on general aviation airports. General aviation airports have taxiway widths between 40 and 60 ft.

Figure 2.16 25 Passenger Class II Threeview

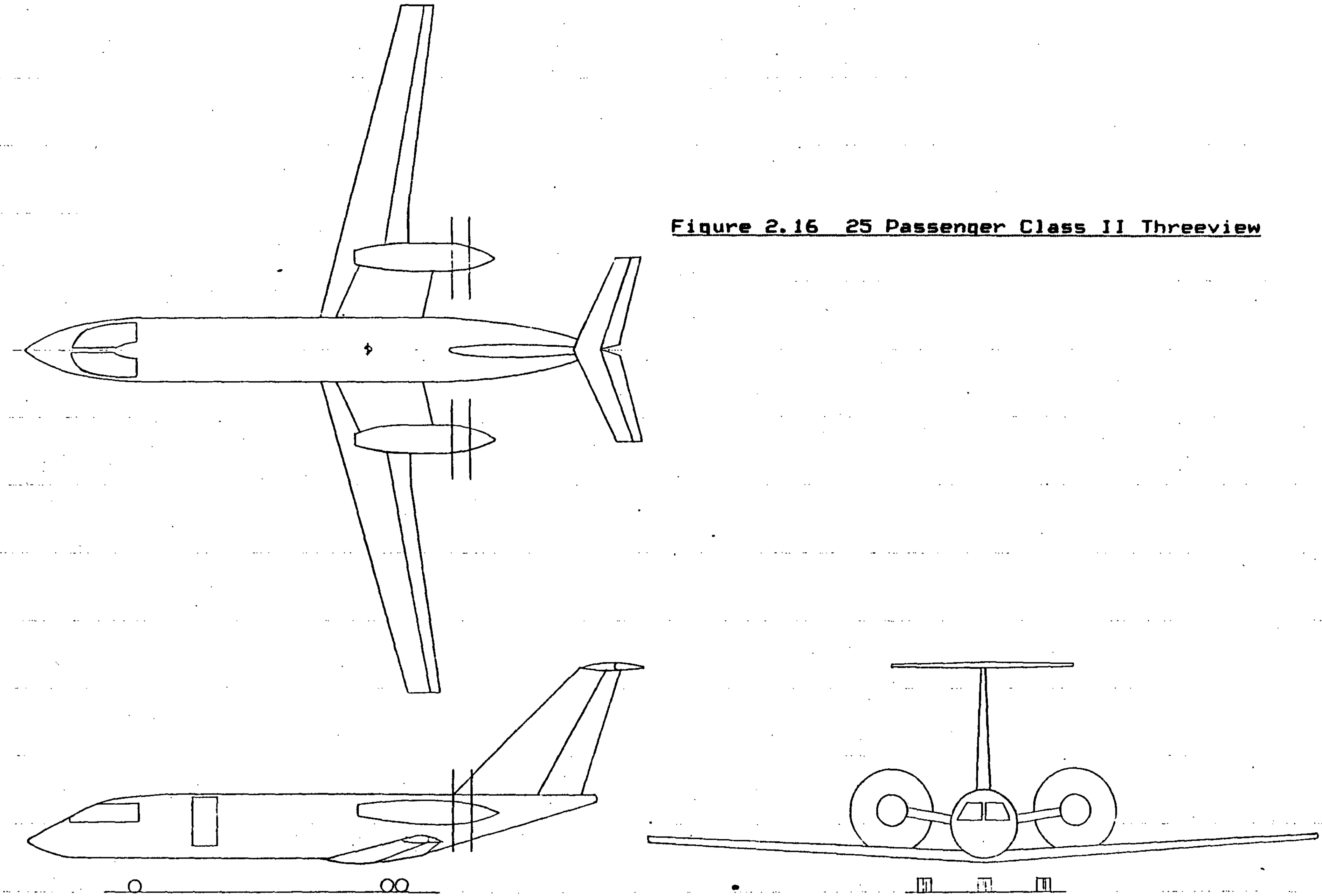

TABLE 2.3 TABLE OF GEOMETRY FOR THE 25 PASSENGER COMMUTER

	WING	HORIZONTAL TAIL	VERTICAL TAIL
S ft^2	592	120	170
b ft	84.3	26.6	15.4
$\bar{c}$ ft	7.45	4.68	12
A	12	5.88	1.40
Λ_{LE}	15°	25°	45°
λ	.4	.5	.33
t/c	.13	.11	.11
Airfoil	NLF	NLF (inv)	NLF (sym)
Γ	3°	0°	0°
i	0°	0°	0°
ϵ_t	-3°	0°	0°
		elevator chord ratio .35	rudder chord ratio .35

Aileron: chord ratio .30
span ratio .85 to .92

Spoiler: chord ratio .10
span ratio .50 to .85

Flap: chord ratio .30
span ratio .11 to 1.0

	FUSELAGE	CABIN INTERIOR	OVERALL
Length ft	71.4	28.7	72.6
Height in	96	76	320
Width in	96	91	852

Figure 2.17 36 Passenger Class II Threeview

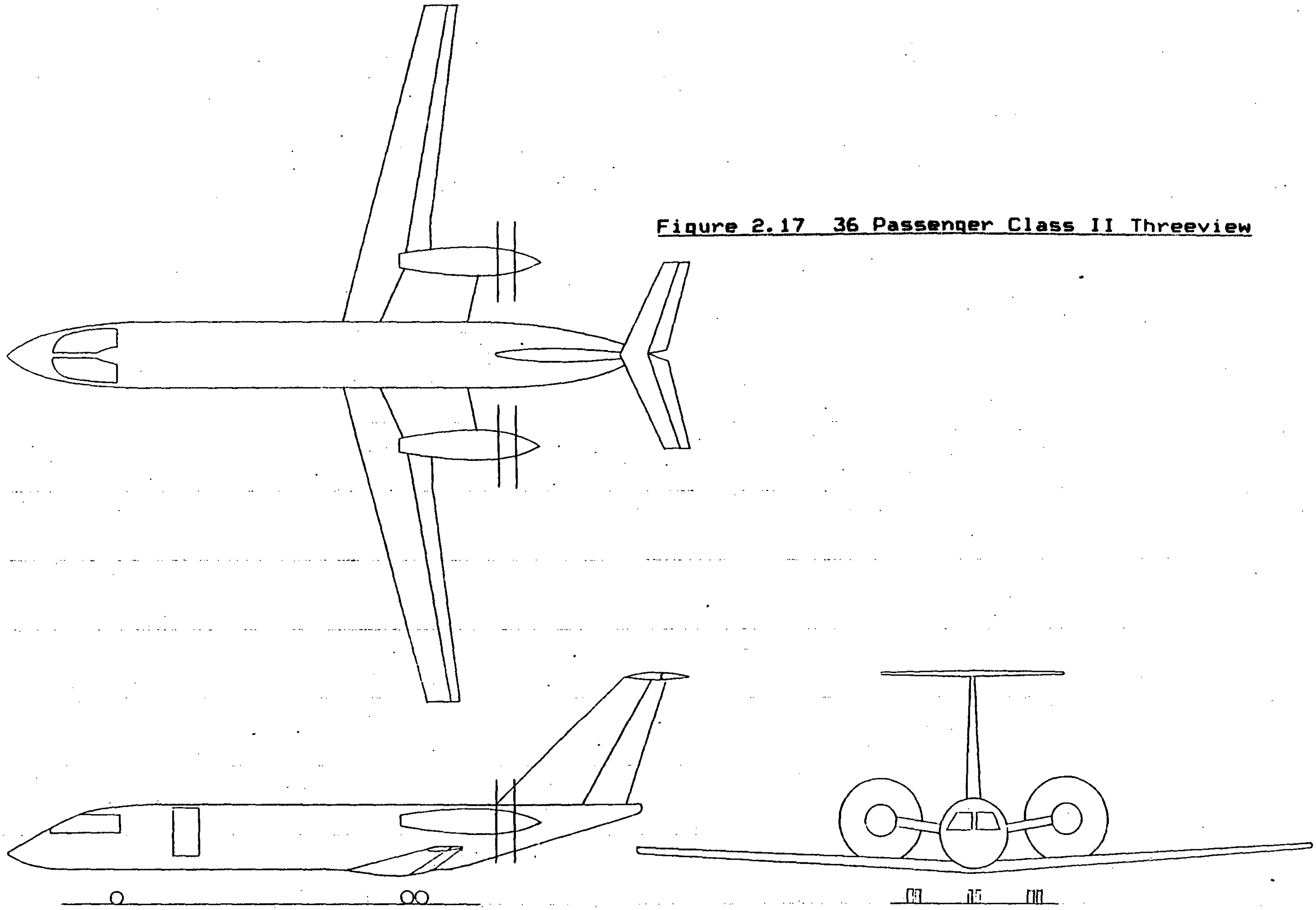

TABLE 2.4 TABLE OF GEOMETRY FOR THE 36 PASSENGER COMMUTER

	WING	HORIZONTAL TAIL	VERTICAL TAIL
S ft^2	592	120	170
b ft	84.3	26.6	15.4
$\bar{c}$ ft	7.45	4.68	12
A	12	5.88	1.40
Λ_{LE}	15°	25°	45°
λ	.4	.5	.33
t/c	.13	.11	.11
Airfoil	NLF	NLF (inv)	NLF (sym)
Γ	3°	0°	0°
i	0°	0°	0°
ϵ_t	-3°	0°	0°
		elevator chord ratio .35	rudder chord ratio .35

Aileron: chord ratio .30
span ratio .85 to .92

Spoiler: chord ratio .10
span ratio .50 to .85

Flap: chord ratio .30
span ratio .11 to 1.0

	FUSELAGE	CABIN INTERIOR	OVERALL
Length ft	79.4	36.7	80.6
Height in	96	76	320
Width in	96	91	852

Figure 2.18 50 Passenger Class II Threeview

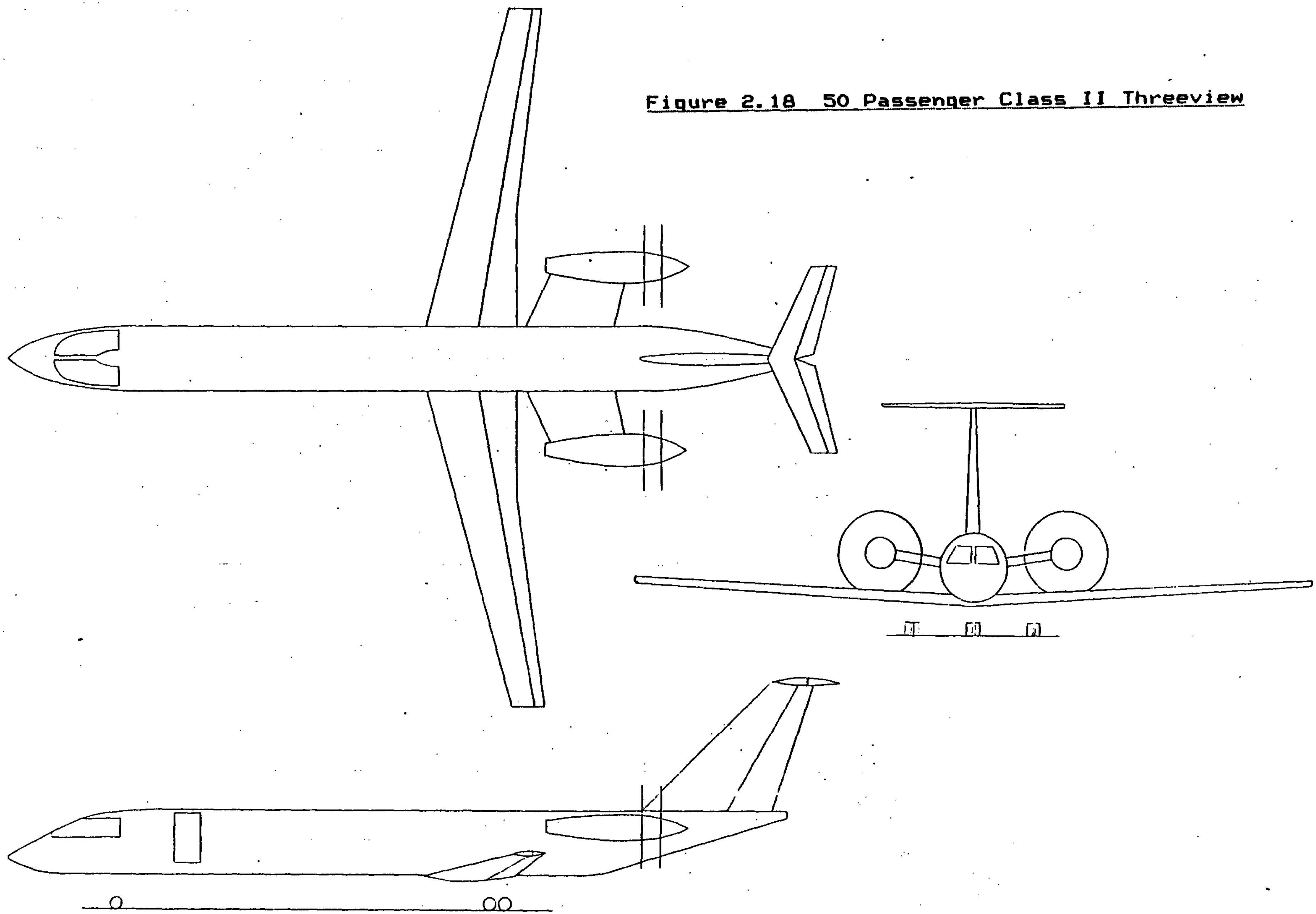

TABLE 2.5 TABLE OF GEOMETRY FOR THE 50 PASSENGER COMMUTER

	WING	HORIZONTAL TAIL	VERTICAL TAIL
S ft^2	592	120	170
b ft	84.3	26.6	15.4
$\bar{c}$ ft	7.45	4.68	12.0
A	12	5.88	1.40
Λ_{LE}	15°	25°	45°
λ	.4	.7	.3
t/c	.13	.11	.11
Airfoil	NLF	NLF (inv)	NLF (sym)
Γ	3°	0°	0°
i	0°	0°	0°
ε_t	−3°	0°	0°
		elevator chord ratio .35	rudder chord ratio .35

Aileron: chord ratio .30
span ratio .85 to .92

Spoiler: chord ratio .10
span ratio .50 to .85

Flap: chord ratio .15
span ratio .11 to 1.0

	FUSELAGE	CABIN INTERIOR	OVERALL
Length ft	96.9	54.2	98.2
Height in	96	76	320
Width in	96	91	852

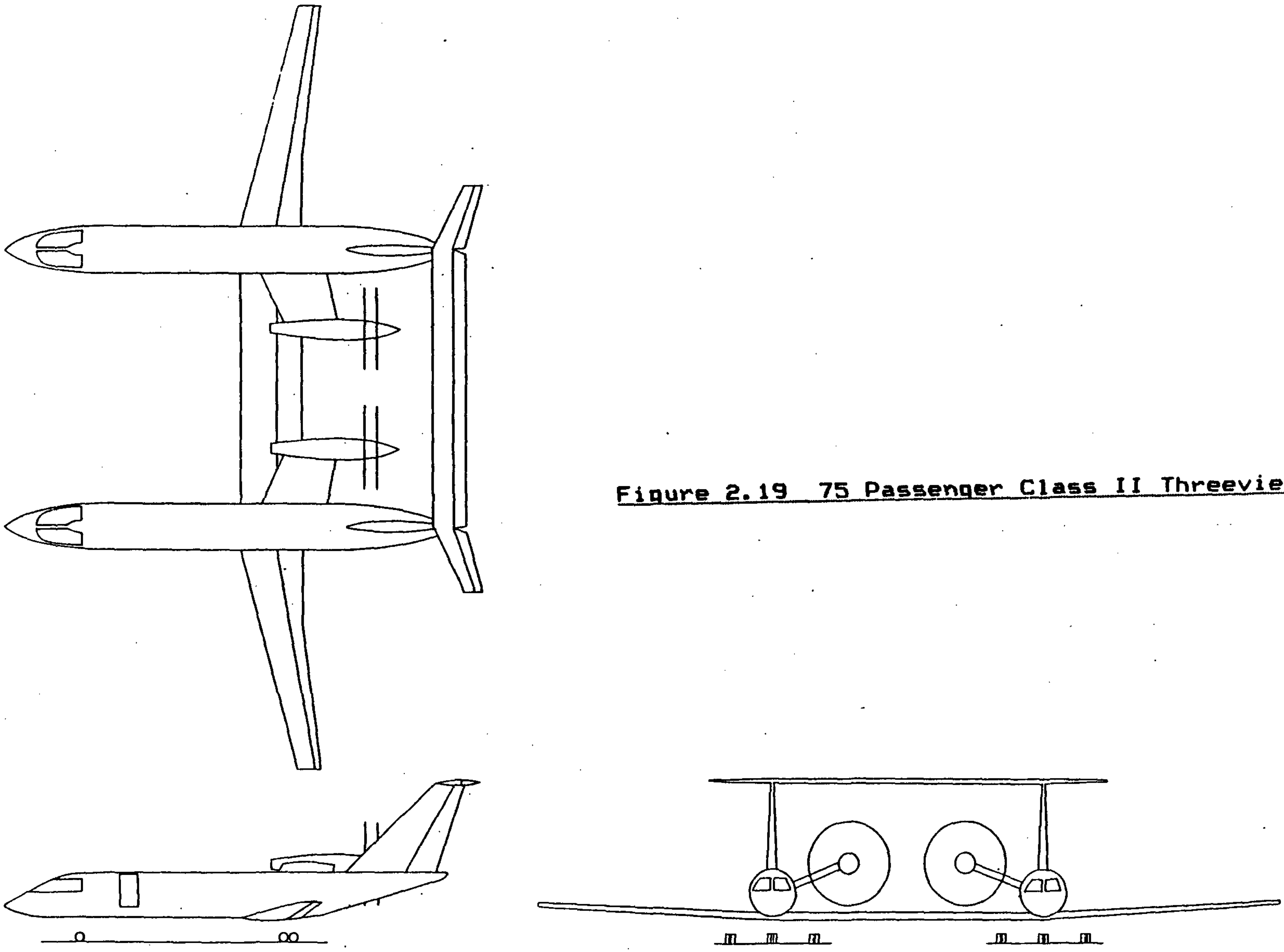

Figure 2.19 75 Passenger Class II Threeview

TABLE 2.6 TABLE OF GEOMETRY FOR THE 75 PASSENGER COMMUTER

	WING	HORIZONTAL TAIL	VERTICAL TAIL
S ft^2	1182	410	340
b ft	132.5	74.77	15.4
$\bar{c}$ ft	8.97	5.63	12
A	14.85	13.6	1.40
Λ_{LE}	11.5°	4°	45°
λ	.4	.5	.33
t/c	.13	.11	.11
Airfoil	NLF	NLF (inv)	NLF (sym)
Γ	3°	0°	0°
i	0°	0°	0°
ε_t	-3°	0°	0°
		elevator chord ratio .35	rudder chord ratio .35

Aileron: chord ratio .30
span ratio .91 to .98

Spoiler: chord ratio .10
span ratio .50 to .90

Flap: chord ratio .30
span ratio .11 to 1.0

	FUSELAGE	CABIN INTERIOR	OVERALL
Length ft	79.4	36.7	80.6
Height in	96	76	320
Width in	96	91	852

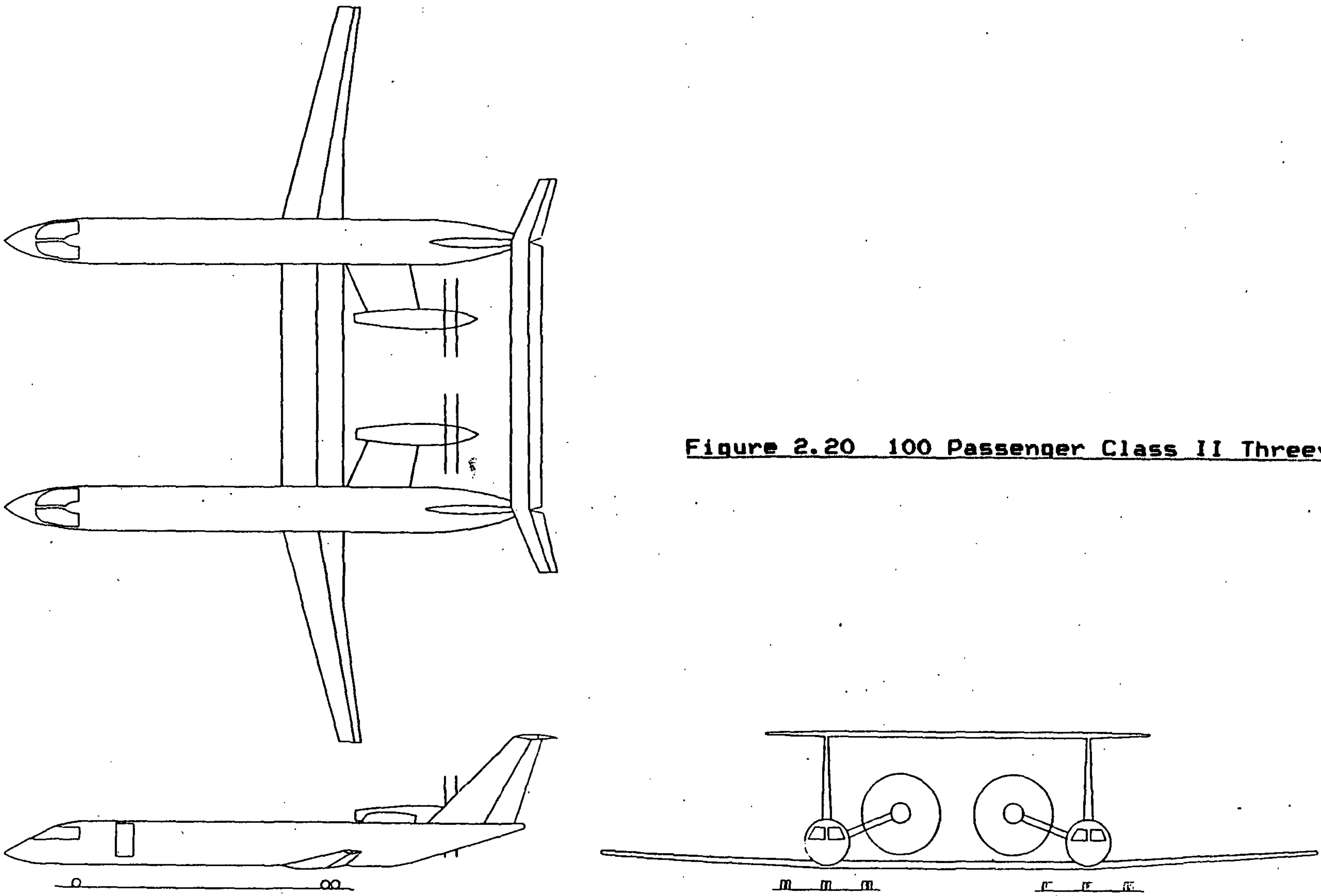

Figure 2.20 100 Passenger Class II Threeview

TABLE 2.7 TABLE OF GEOMETRY FOR THE 100 PASSENGER COMMUTER

	WING	HORIZONTAL TAIL	VERTICAL TAIL
S ft^2	1182	410	340
b ft	132.5	74.77	15.4
$\bar{c}$ ft	8.97	5.63	12
A	14.85	13.6	1.40
Λ_{LE}	11.5°	4°	45°
λ	.4	.5	.33
t/c	.13	.11	.11
Airfoil	NLF	NLF (inv)	NLF (sym)
Γ	3°	0°	0°
i	0°	0°	0°
ε_t	-3°	0°	0°
		elevator chord ratio .35	rudder chord ratio .35

Aileron: chord ratio .30
span ratio .91 to .98

Spoiler: chord ratio .10
span ratio .50 to .90

Flap: chord ratio .30
span ratio .11 to 1.0

	FUSELAGE	CABIN INTERIOR	OVERALL
Length ft	96.9	54.2	98.2
Height in	96	76	320
Width in	96	91	852

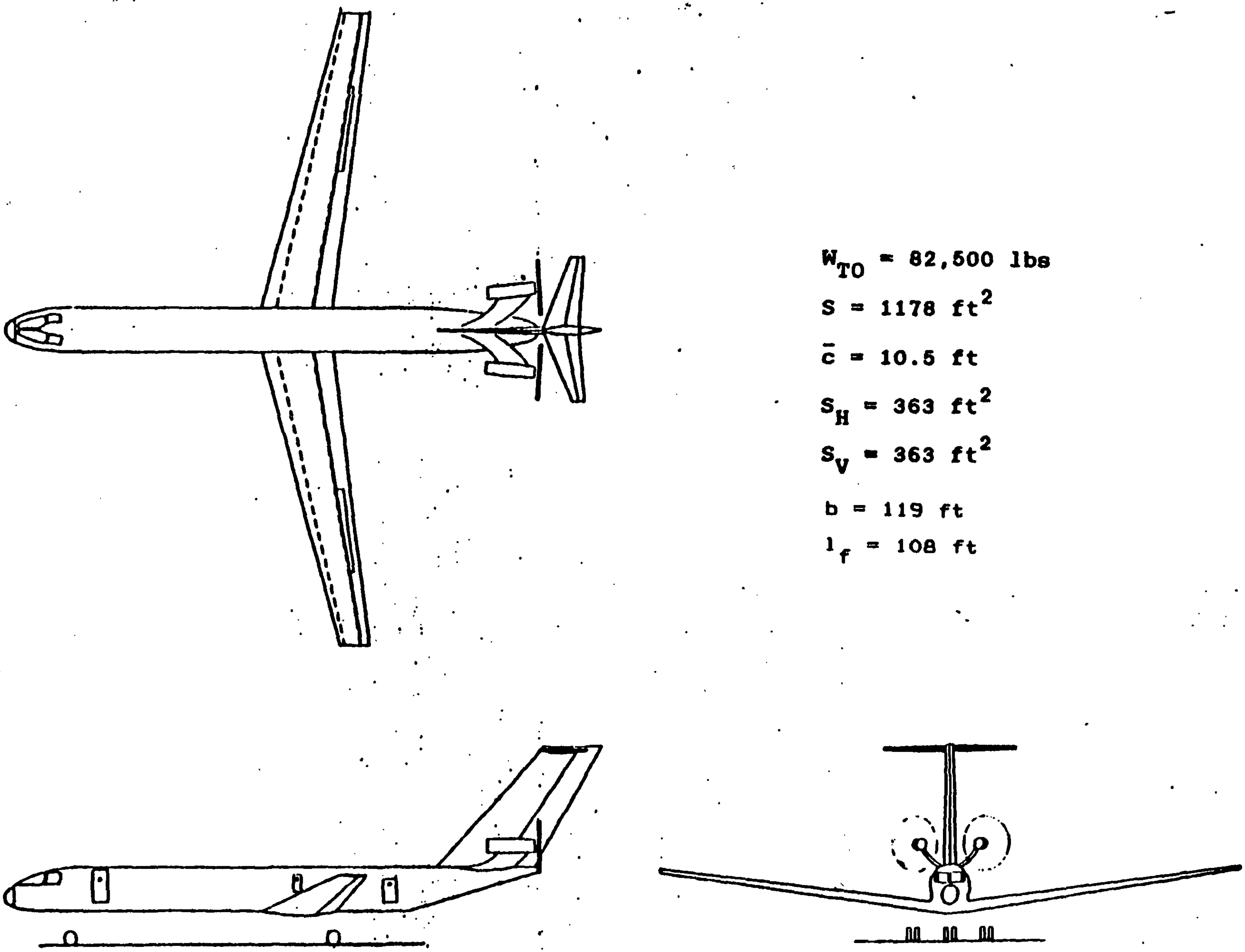

FIGURE 2.21 3-VIEW OF THE 75 PASSENGER MODEL

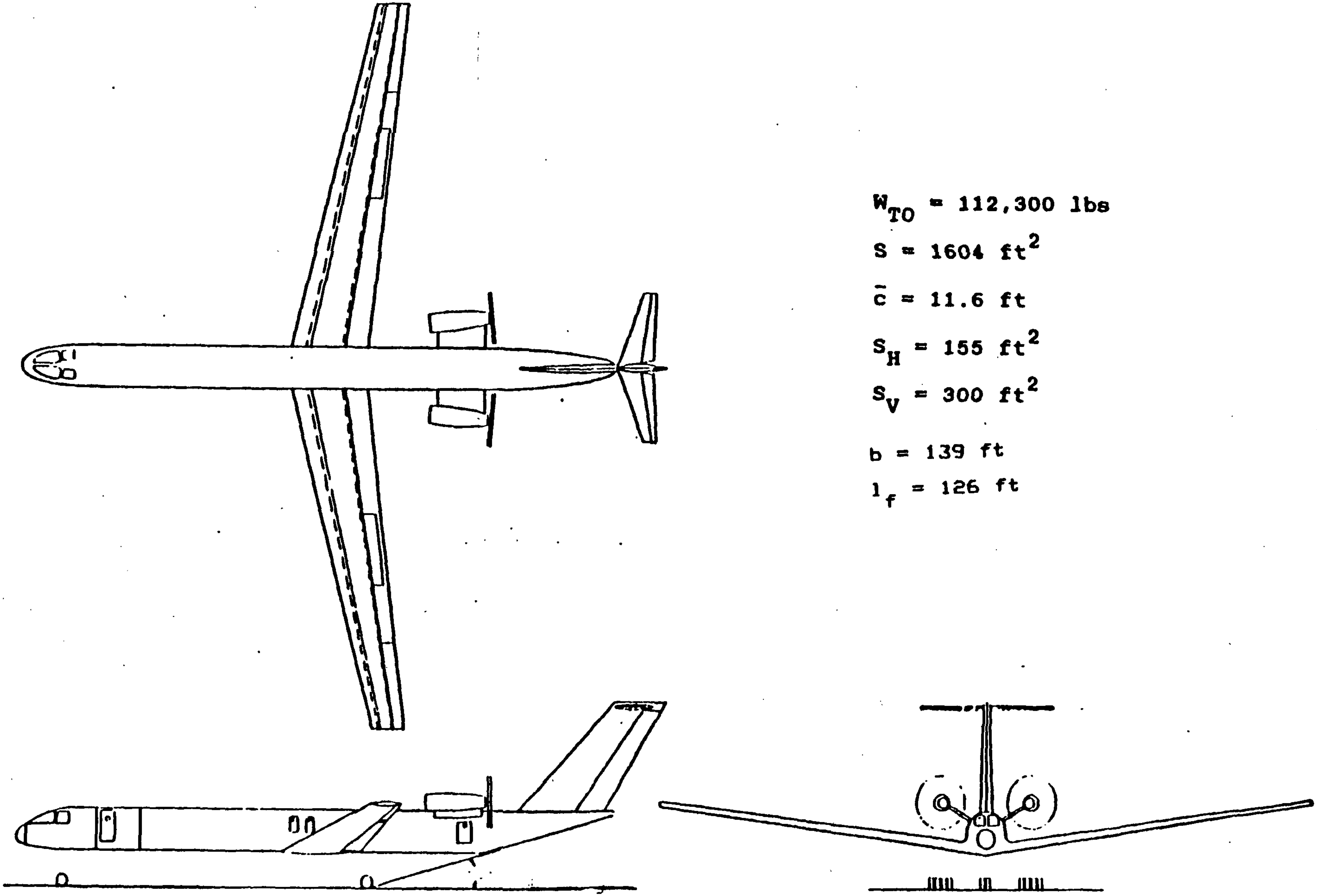

FIGURE 2.22 3-VIEW OF THE 100 PASSENGER MODEL

3.0 MASS PROPERTIES OF THE COMMUTER FAMILY

The purpose of this chapter is to present the weights and balance of the airplanes. The airplane inertias and take-off weight sensitivities are also presented.

3.1 Weight and Balance

The class II weight breakdowns taken from Reference 2 are used and the center of gravity excursion ranges are computed. Appendix B contains the weight and balance spreadsheets for all the airplanes. Figures 3.1 to 3.5 contain the excursion diagrams for the commuter family.

3.2 Airplane Inertias

Airplane inertias were calculated. Appendix B summarizes the inertias for the commuter family.

Table 3.1 - Airplane Inertias

		W_{TO}			W_{OE}	
Model	Ixx	Iyy	Izz	Ixx	Iyy	Izz
25	103778	131896	188392	66528	121578	169310
36	125220	237382	339291	69710	207940	255999
50	141865	465510	580046	73363	408670	457113
75	1355496	505928	1779110	761328	441252	1125135
100	1646875	769820	2326135	888448	653359	1455491

*Inertias in slug-ft^2

Figures 3.6 thru 3.8 compare the inertias of the commuter family to some existing airplanes. As seen from the figures, the inertias compare favorably with existing airplanes.

The rolling moment of inertia of the twin body configurations is larger than existing airplanes as is expected.

3.3 Take-off Weight Sensitivities

Using methods in Reference 8. the take-off weight sensitivities are calculated. Results are summarized in Table 3.2. These sensitivities compare with existing transports and regionals.

Table 3.2 - Take-off Weight Sensitivities Summary

Sensitivity	Airplane					
	25	36	50	75	100	(units)
$\partial W_{TO}/\partial W_{PL}$	5.09	4.45	3.92	4.36	3.94	(lb/lb)
$\partial W_{TO}/\partial W_{E}$	1.63	1.62	1.61	1.58	1.57	(lb/lb)
$\partial W_{TO}/\partial R$	8.54	8.54	8.16	14.24	15.20	(lb/nm)
$\partial W_{TO}/\partial c_{p}$	33755	33765	32288	76759	81963	(lb/lb/hp/hr)
$\partial W_{TO}/\partial L/D$	-738	-689	-599	-1342	-1433	(lb)
$\partial W_{TO}/\partial \eta_{p}$	-12011	-12014	-11489	-27312	-29164	(lb)

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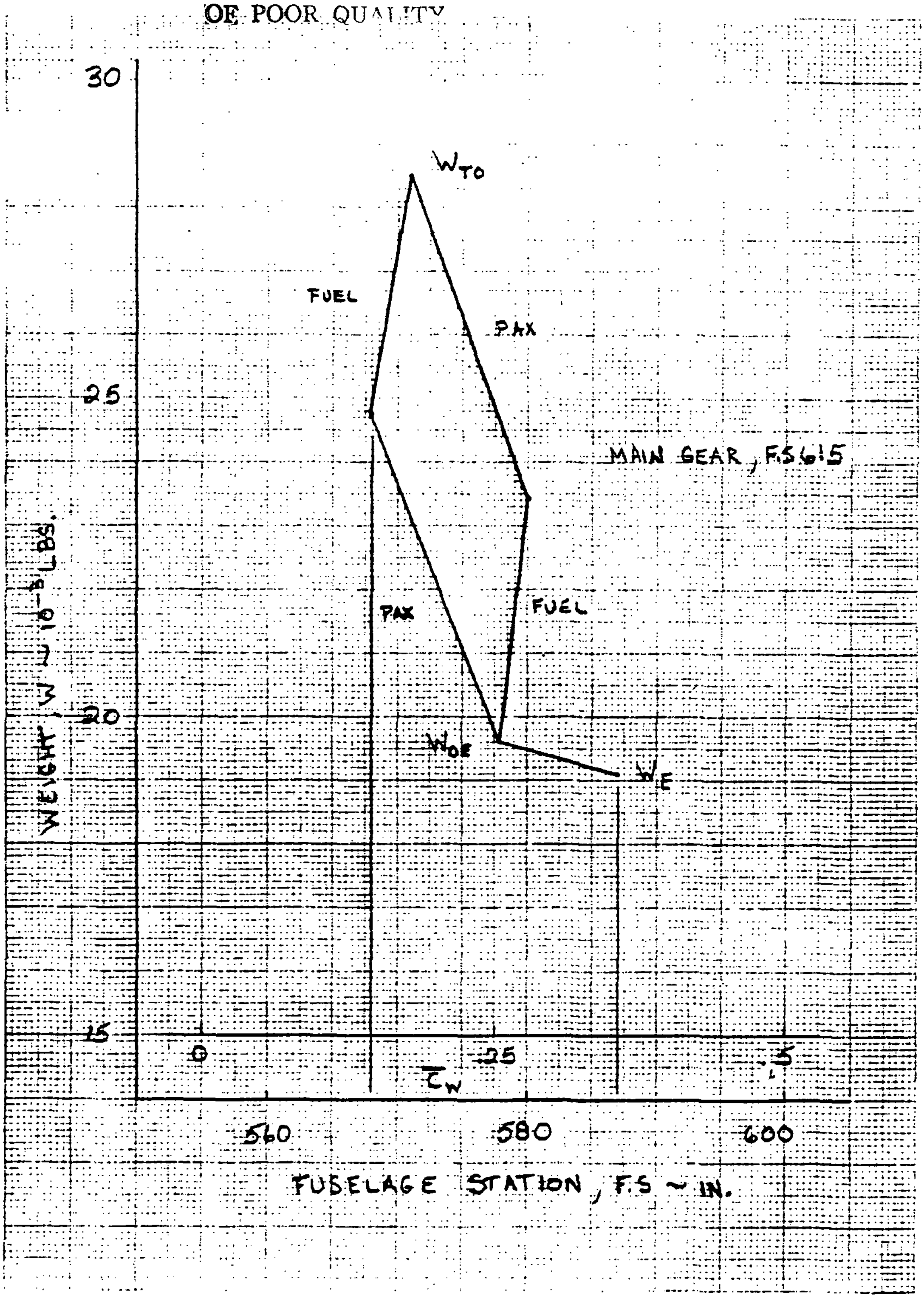

CALC	3-25-87	TRC	REVISED	DATE	Figure 3.1 Center of Gravity Excursion Diagram for the 25 Passenger Model
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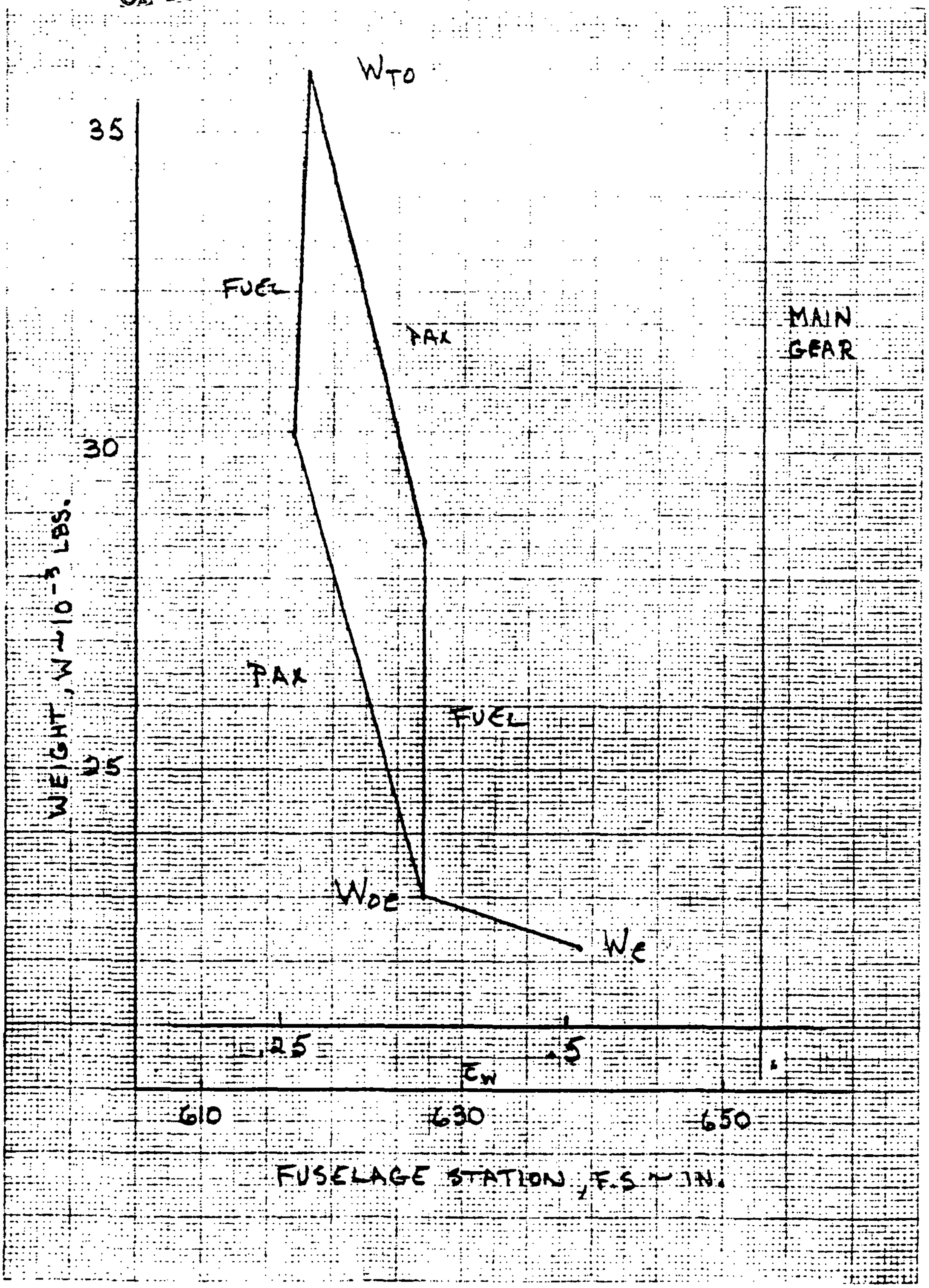

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Figure 3.2 Center of Gravity Excursion Diagram for the 36 Passenger Model

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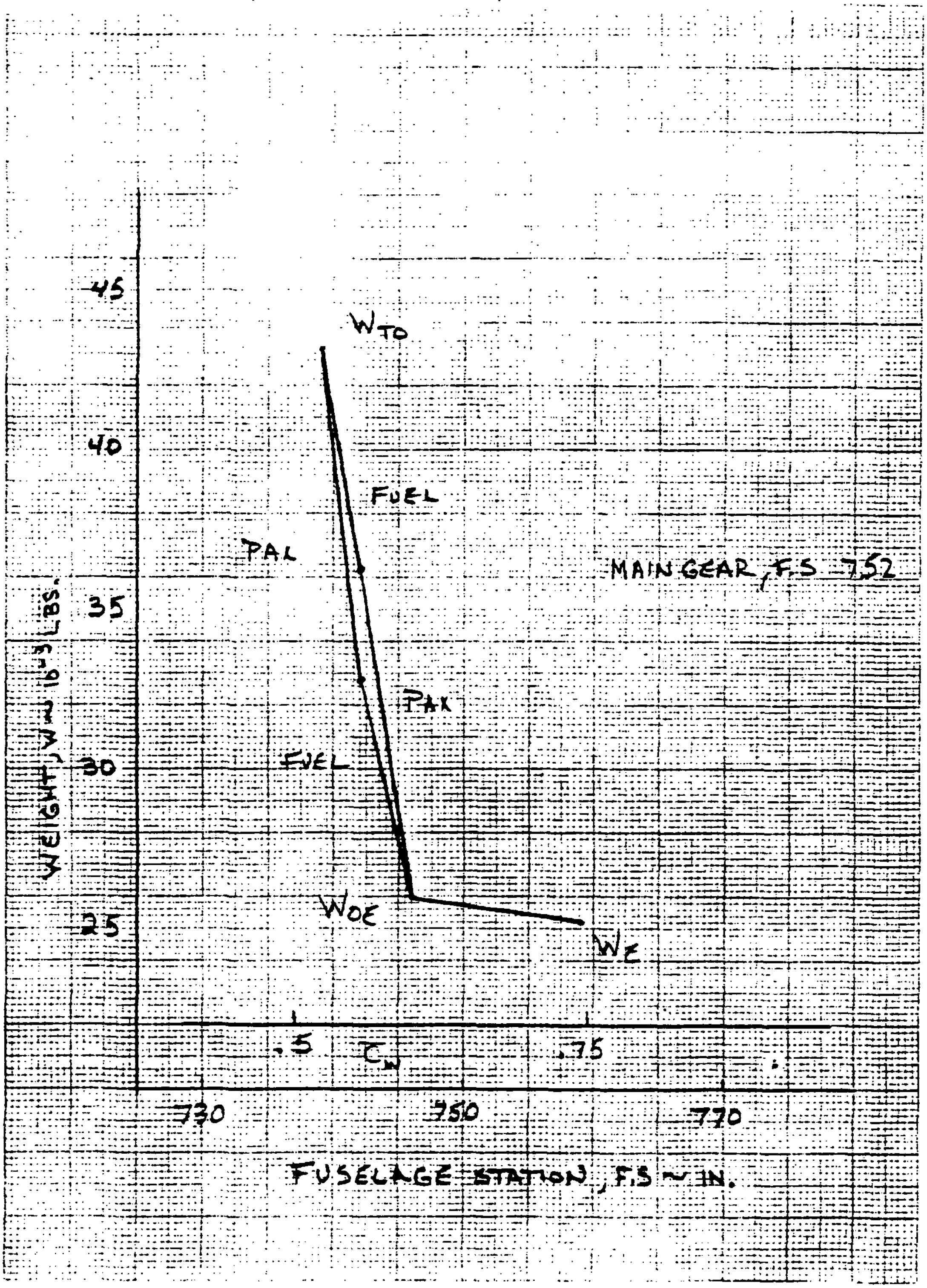

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Figure 3.3 Center of Gravity Excursion Diagram for the 50 Passenger Model

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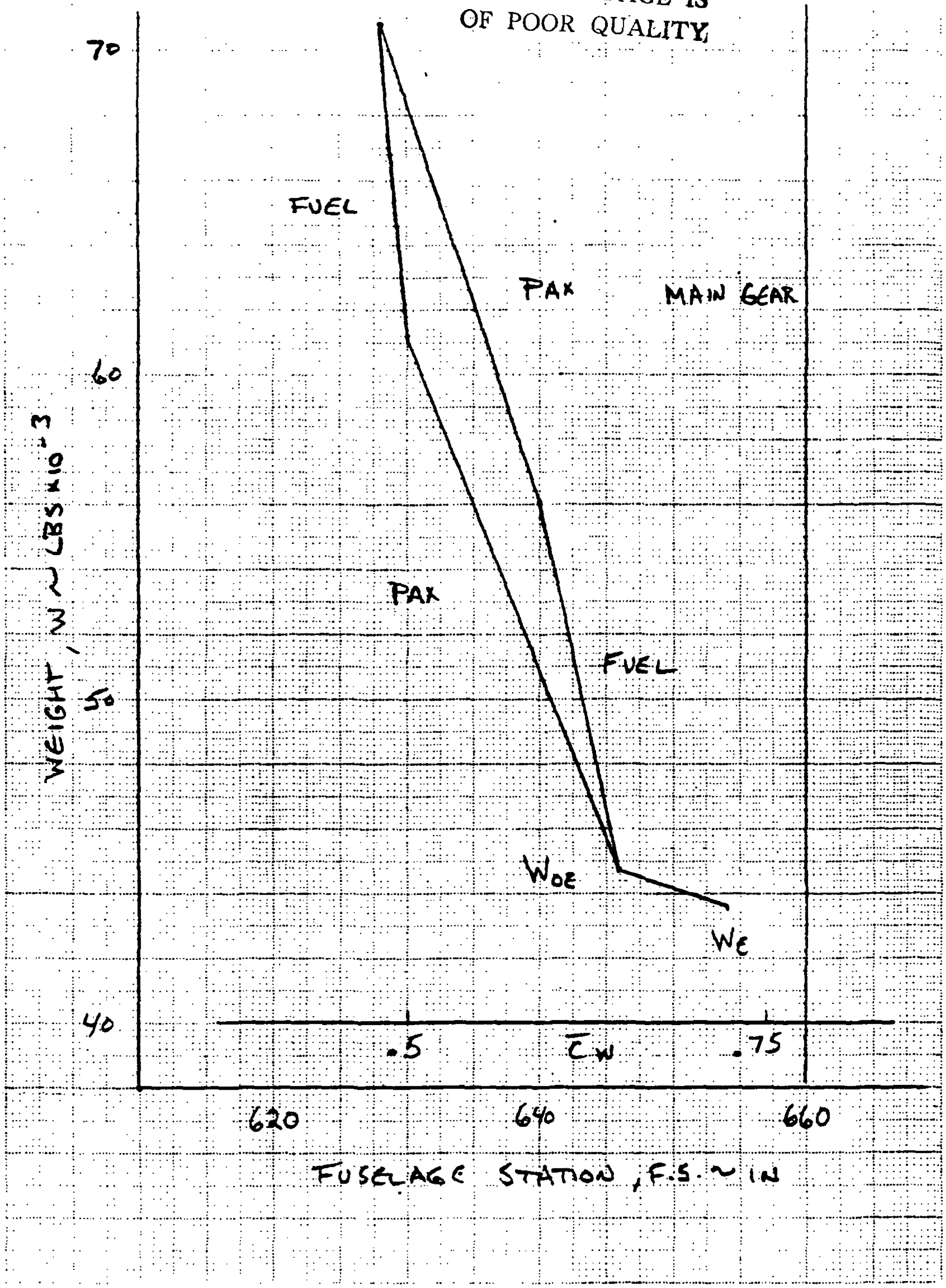

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Figure 3.4 Center of Gravity Excursion Diagram for the 75 Passenger Model

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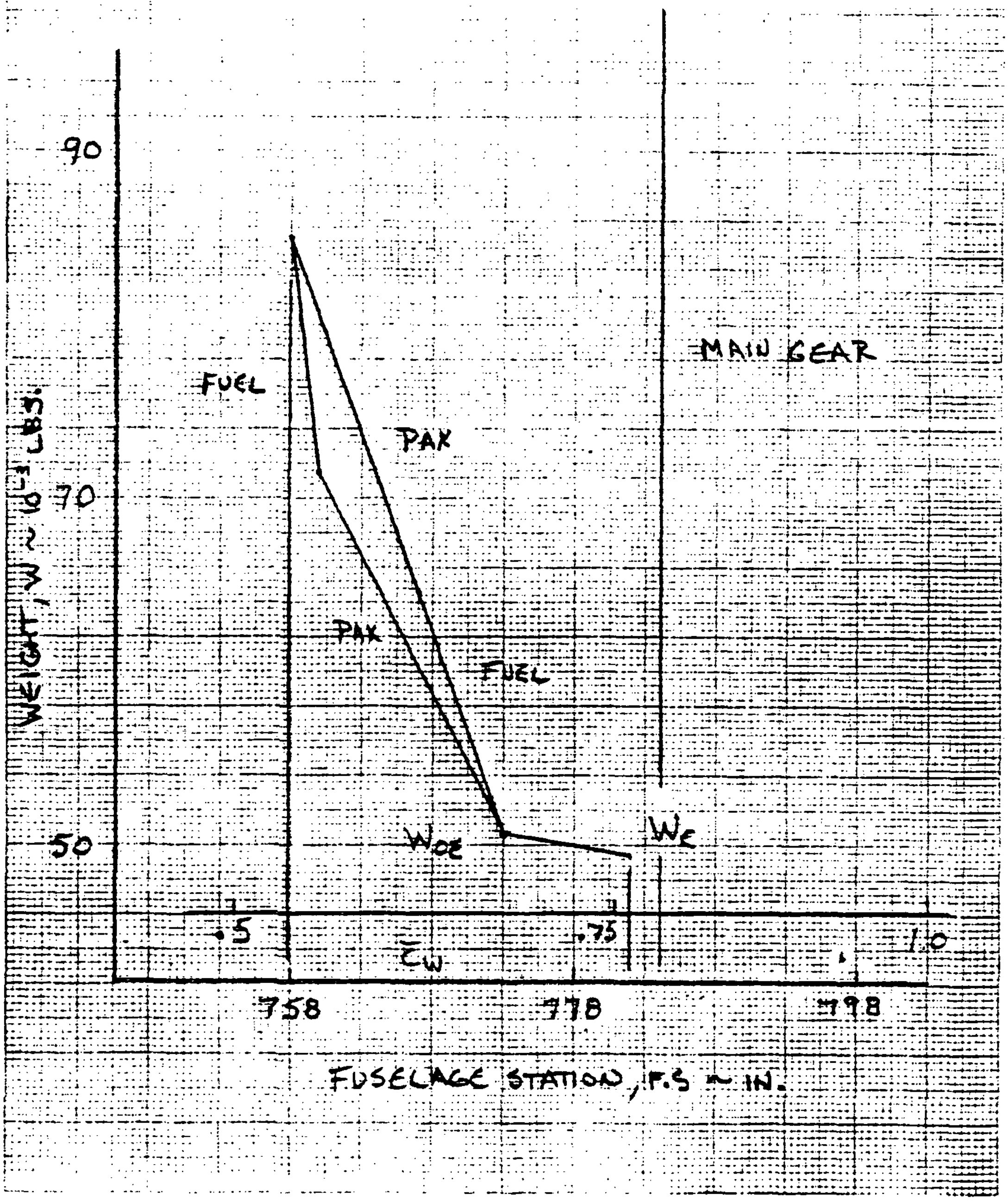

CALC	3-25-87	TRC	REVISED	DATE	Figure 3.5 Center of Gravity Excursion Diagram for the 100 Passenger Model	
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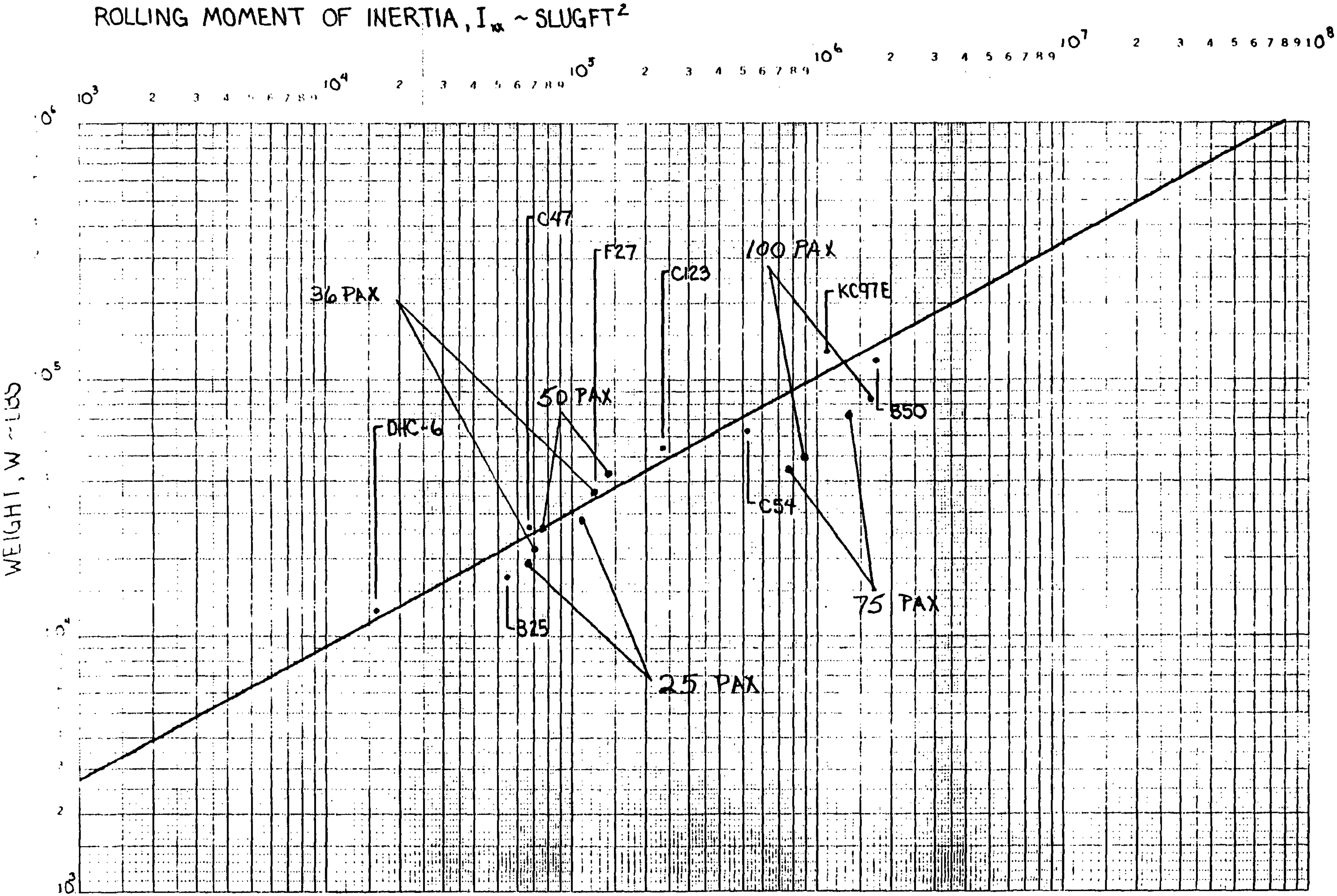

Figure 3.6 Rolling Moment of Inertia Comparison

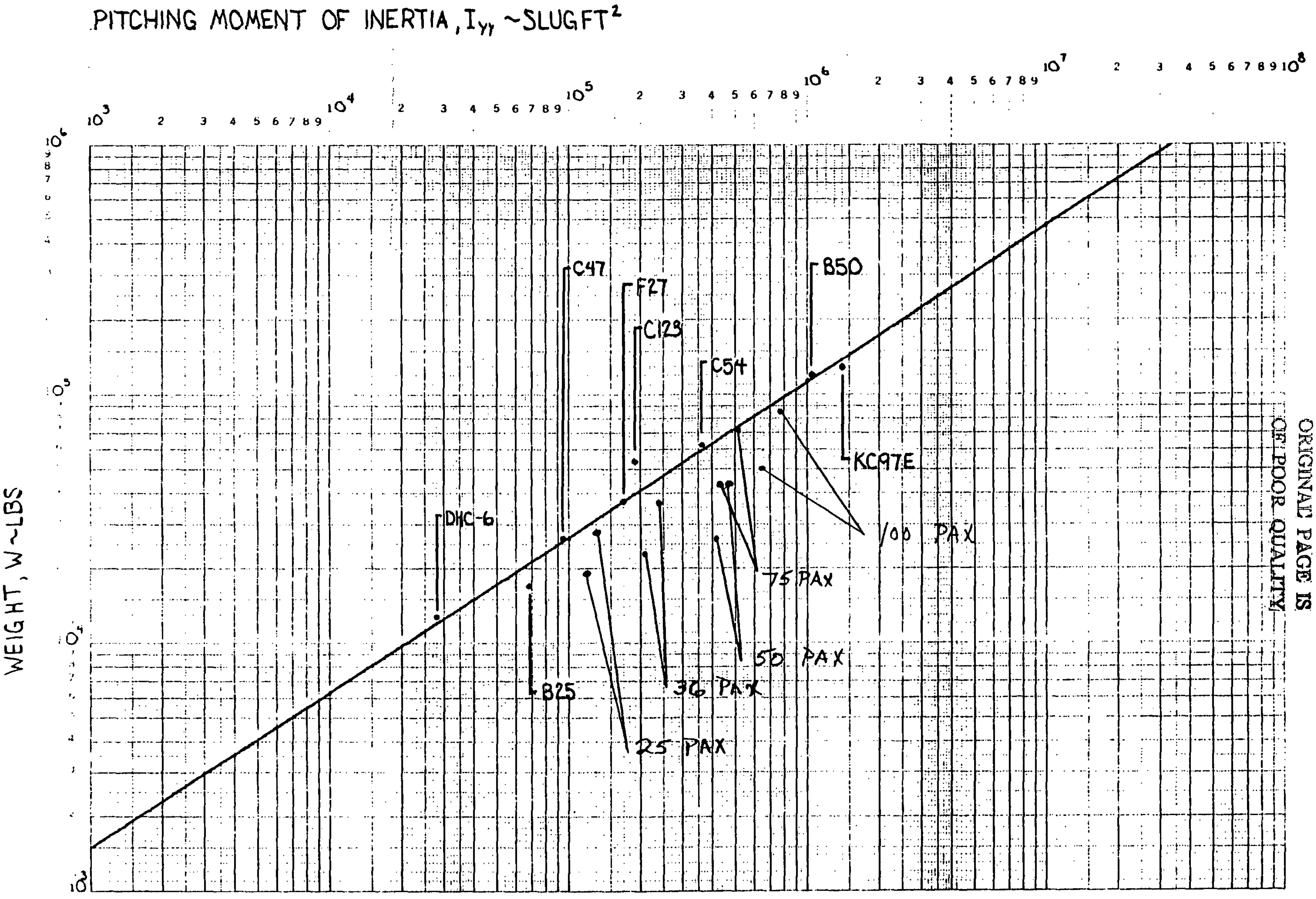

Figure 3.7 Pitching Moment of Inertia Comparison

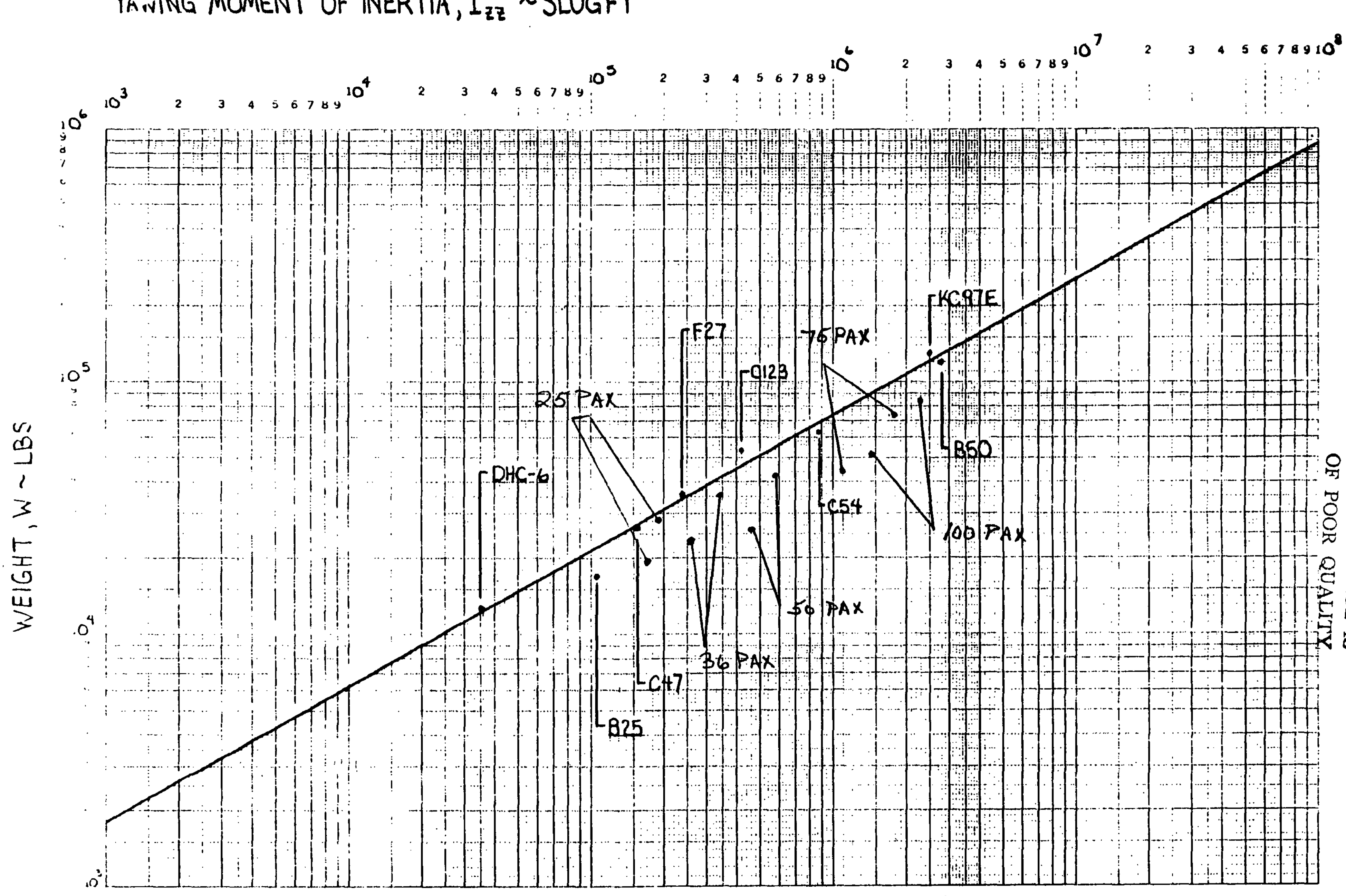

Figure 3.8 Yawing Moment of Inertia Comparison

4. STABILITY AND CONTROL ANALYSIS

The purpose of this chapter is to address the stability and control considerations made during the design of the family of commuter airplanes. The following topics are included in this chapter:

1) Commonality Considerations
2) Wing Maximum Lift
3) Wing Lift Curves
4) Trim Diagrams
5) Handling Qualities
6) Take-off Rotation
7) Engine-out Requirements

The necessary engineering calculations are presented in Appendix C. Most of the design calculations were done using a spreadsheet program on a personal computer. Since a change in tail size, or the movement of any of the components changed the stability and control calculations for the entire family, these programs proved to be invaluable.

4.1 Commonality Considerations

Obtaining as high a degree of commonality as possible was a major theme throughout the design process. Commonality took the form of common tail areas, wing sections, and wing placement. These affected the outcome of the weight and balance as well as the stability and control calculations. Common features, from a stability and control viewpoint, are discussed below.

1) Common Wing - The 25, 36, and 50 passenger airplanes have a common wing. The 75 and 100 passenger twin-bodies use the same outboard section, and have a common center wing section between them. This resulted in oversized wings for the smaller airplanes. As a result, the flap deflections required to meet the field requriements could be lowered (see Table 4.1). Note that the flap deflections on the 36 - 75 and 50 - 100 airplanes are identical, to retain commonality between these pairs of airplanes.

2) Wing placement between the 36 - 75 and 50 - 100 airplanes should ideally be common. This idea was feasible on the 36 - 75 pair, but not feasible on the 50 - 100 pair. Common wing

placement on the 50 - 100 pair resulted in an unacceptable static margin, and gear placement problems.

3) Common Horizontal Tails - The 25, 36 and 50 passenger airplanes use a common horizontal tail. The 75 and 100 passenger airplanes use the same tail for their outboard sections, and a common tailbar to join the airplanes. The large tail sizes were required because of the large pitching moment generated by the advanced turboprops at minimum control speed.

4) Common Vertical Tail and Tailcone - The vertical tail is common to all airplanes in the family. The large vertical tail is required by the 25, 36, and 50 passenger airplanes to trim in an engine out flight condition. The used of the advanced turboprops required that the engines be mounted away from the fuselage, which creates a very large yawing moment if one engine fails.

5) The location of the engines was also subject to a trade study. Three requirements had to be balanced against each other:

a) Propeller clearance requirements
b) Engine-out conditions (horizontal placement)
c) Pitch trim with full power on approach (vertical placement)

Condition (a) limited the height of the engines from the bottom of the fuselage, condition (b) sized the vertical tail, and condition (c) sized the horizontal tail.

4.2 Wing Maximum Lift

Using a method in Reference 9, Figures 4.1 and 4.2 were generated. These figures show that the low speed wing $C_{L_{max}}$ is 1.5. The cruise $C_{L_{max}}$ of the wing is 1.25. During initial performance sizng of the baseline configurations, a clean $C_{L_{max}}$ of 1.4 was assumed for all the airplanes. The wing design incorporated into the commuter family will generate the required clean $C_{L_{max}}$. The flap deflections used on each airplane are listed in Table 4.1. These flap settings were selected to obtain the needed increment in $C_{L_{max}}$ to meet the field length requirements.

Table 4.1 - Flap Deflections for the Commuter Family

25 Passenger:	$\delta_f = 0°$	$\Delta C_L = 0$	$\Delta C_M = 0$
36 Passenger:	$\delta_f = 20°$	$\Delta C_L = .82$	$\Delta C_M = -.349$
50 Passenger:	$\delta_f = 30°$	$\Delta C_L = .94$	$\Delta C_M = -.387$
75 Passenger:	$\delta_f = 20°$	$\Delta C_L = .94$	$\Delta C_M = -.250$
100 Passneger:	$\delta_f = 30°$	$\Delta C_L = 1.08$	$\Delta C_M = -.280$

4.3 Wing Lift Curves

The wing lift curves are shown in Figures 4.3 and 4.4, with the corresponding equations listed in Table 4.2. Note that the three single body airplanes use a common wing, as do the two twinbody airplanes. However, the flap deflections are different, as discussed in subsection 4.1.

Table 4.2 - Lift Curve Equation for the Commuter Family

25 pax	Cruise:	$C_L = 0.17 + 0.097\alpha + 0.007\delta_E$	
	Approach:	$C_L = 0.17 + 0.099\alpha + 0.008\delta_E$	(no flaps)
36 pax	Cruise:	$C_L = 0.17 + 0.097\alpha + 0.007\delta_E$	
	Approach:	$C_L = 0.17 + 0.099\alpha + 0.008\delta_E + .83$	(flaps 20°)
50 pax	Cruise:	$C_L = 0.17 + 0.097\alpha + 0.007\delta_E$	
	Approach:	$C_L = 0.17 + 0.099\alpha + 0.008\delta_E + .94$	(flaps 30°)
75 pax	Cruise:	$C_L = 0.17 + 0.114\alpha + 0.016\delta_E$	
	Approach:	$C_L = 0.17 + 0.115\alpha + 0.016\delta_E + .94$	(flaps 20°)
100 pax	Cruise:	$C_L = 0.17 + 0.114\alpha + 0.016\delta_E$	
	Approach:	$C_L = 0.17 + 0.115\alpha + 0.016\delta_E + 1.08$	(flaps 30°)

4.4 Trim Diagrams

The trim diagrams for the family of commuter airplanes are presented in Figures 4.5 through 4.18. Several design features are incorporated into the family.

1) In the approach flight condition (V_{MC}) the flaps and powerplants (at full power) create a large negative pitching moment. To attain reasonable trimmed elevator deflections, an inverted airfoil on the horizontal tail is used. This feature

also reduces the cruise trimmed elevator deflections. The increment in C_{M_o} due to the inverted airfoil section is listed in Table 4.3, and the trimmed elevator deflections required in cruise and approach are listed in Table 4.4

2) To obtain reasonable static margins and longitudinal control power, a horizontal tail bar is used on the twin-body airplanes. The tail bar has a full span elevator, and utilizes a symmetrical airfoil. The use of an inverted airfoil for this section was investigated, but the resulting pitching moment was unacceptable in cruise.

The pitching moment equations for the commuter family are listed in Table 4.5. The following flight conditions are represented in the pitch-trim diagrams (Figures 4.5 to 4.18).

Table 4.3 - Increments in Lift and Pitching Moment Due to the Inverted Airfoil Section on the Horizontal Tail

Airplane	ΔC_{L_o}	ΔC_{M_o} fwd C.G.	ΔC_{M_o} aft C.G.
25 passenger	-0.034	0.138	0.133
36 passenger	-0.034	0.154	0.150
50 passenger	-0.034	0.190	0.187
75 passenger	-0.017	0.064	0.061
100 passenger	-0.017	0.074	0.071

Table 4.4 - Trimmed Elevator Deflections for the Commuter Family

Airplane	Elevator Deflection (deg) Cruise* fwd C.G.	Cruise* aft C.G.	Approach** fwd C.G.	Approach** aft C.G.
25 passenger	-2.77°	-3.56°	5.75°	1.97°
36 passenger	-2.70°	-3.66°	17.73°	13.43°
50 passenger	-3.94°	-4.71°	14.92°	11.49°
75 passenger	-0.84°	-1.05°	13.65°	9.78°
100 passenger	0.22°	-0.93°	15.58°	10.84°

*Cruise Thrust **Full Power, Flaps Down

Table 4.5 - Pitching Moment Equations for the Commuter Family

25 pax:

Cruise, fwd: $C_M = .124 - .224C_L - .028\delta_E - .003(T)$

Cruise, aft: $C_M = .119 - .089C_L - .028\delta_E - .003(T)$

Approach, fwd: $C_M = .134 - .231C_L - .029\delta_E - .112(T)$

Approach, aft: $C_M = .129 - .096C_L - .029\delta_E - .112(T)$

36 pax:

Cruise, fwd: $C_M = .148 - .253C_L - .031\delta_E - .004(T)$

Cruise, aft: $C_M = .144 - .119C_L - .031\delta_E - .004(T)$

Approach, fwd: $C_M = .159 - .260C_L - .032\delta_E - .349(f) - .117(T)$

Approach, aft: $C_M = .155 - .126C_L - .032\delta_E - .349(f) - .117(T)$

50 pax:

Cruise, fwd: $C_M = .207 - .134C_L - .039\delta_E - .008(T)$

Cruise, aft: $C_M = .204 - .061C_L - .039\delta_E - .008(T)$

Approach, fwd: $C_M = .218 - .143C_L - .041\delta_E - .387(f) - .239(T)$

Approach, aft: $C_M = .215 - .070C_L - .041\delta_E - .387(f) - .239(T)$

75 pax:

Cruise, fwd: $C_M = .087 - .114C_L - .056\delta_E - .008(T)$

Cruise, aft: $C_M = .087 - .114C_L - .056\delta_E - .008(T)$

Approach, fwd: $C_M = .096 - .211C_L - .056\delta_E - .250(f) - .361(T)$

Approach, aft: $C_M = .096 - .044C_L - .056\delta_E - .250(f) - .361(T)$

100 pax:

Cruise, fwd: $C_M = .107 - .332C_L - .064\delta_E - .010(T)$

Cruise, aft: $C_M = .107 - .189C_L - .064\delta_E - .010(T)$

Approach, fwd: $C_M = .116 - .323C_L - .064\delta_E - .280(f) - .379(T)$

Approach, aft: $C_M = .116 - .180C_L - .064\delta_E - .280(f) - .379(T)$

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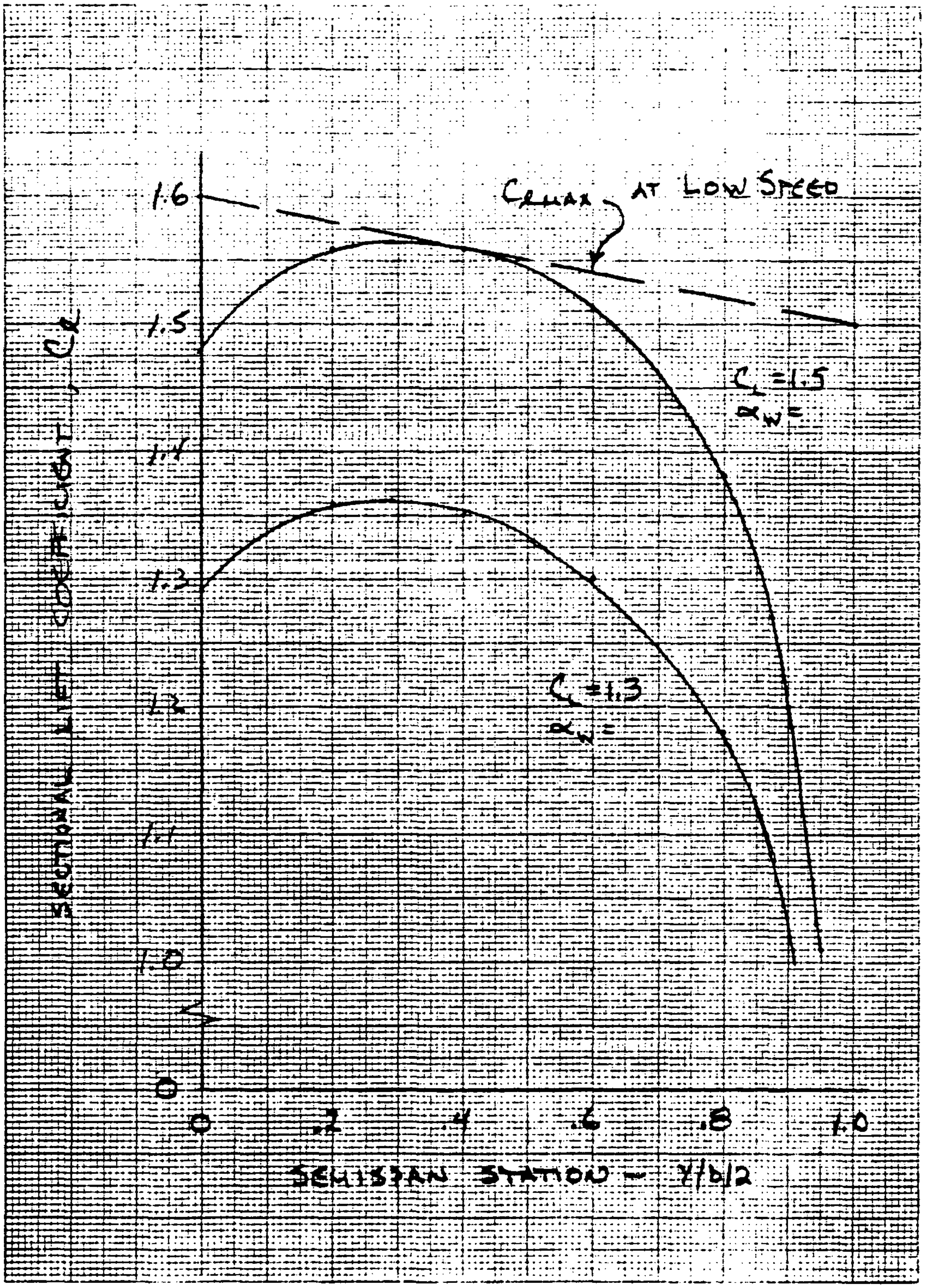

CALC	12-3-86	TRC	REVISED	DATE	FIGURE 4.1 WING MAXIMUM LIFT AT LOW SPEED
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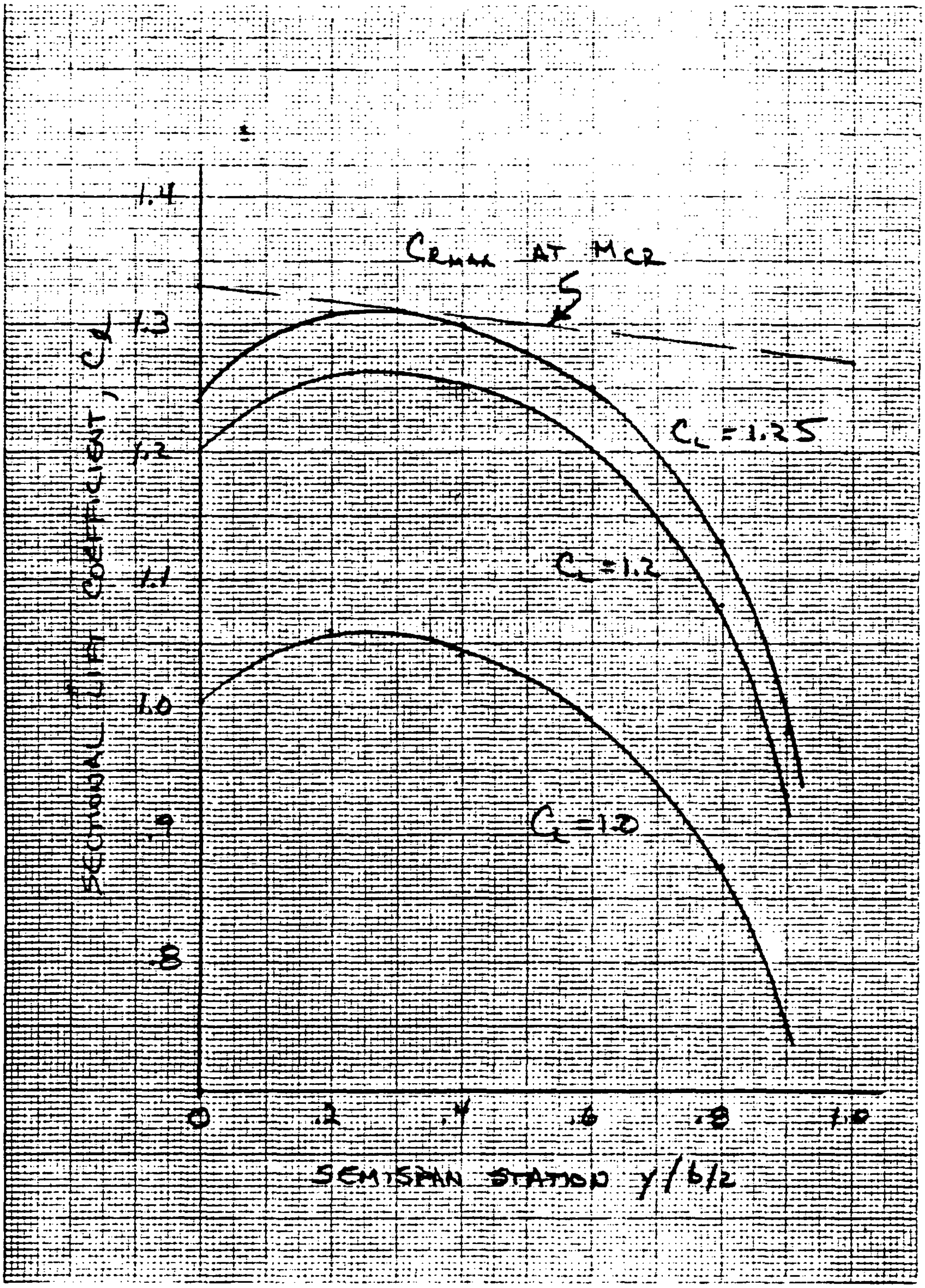

CALC	12-3-86	TRC	REVISED	DATE	FIGURE 4.2 WING MAXIMUM LIFT AT CRUISE
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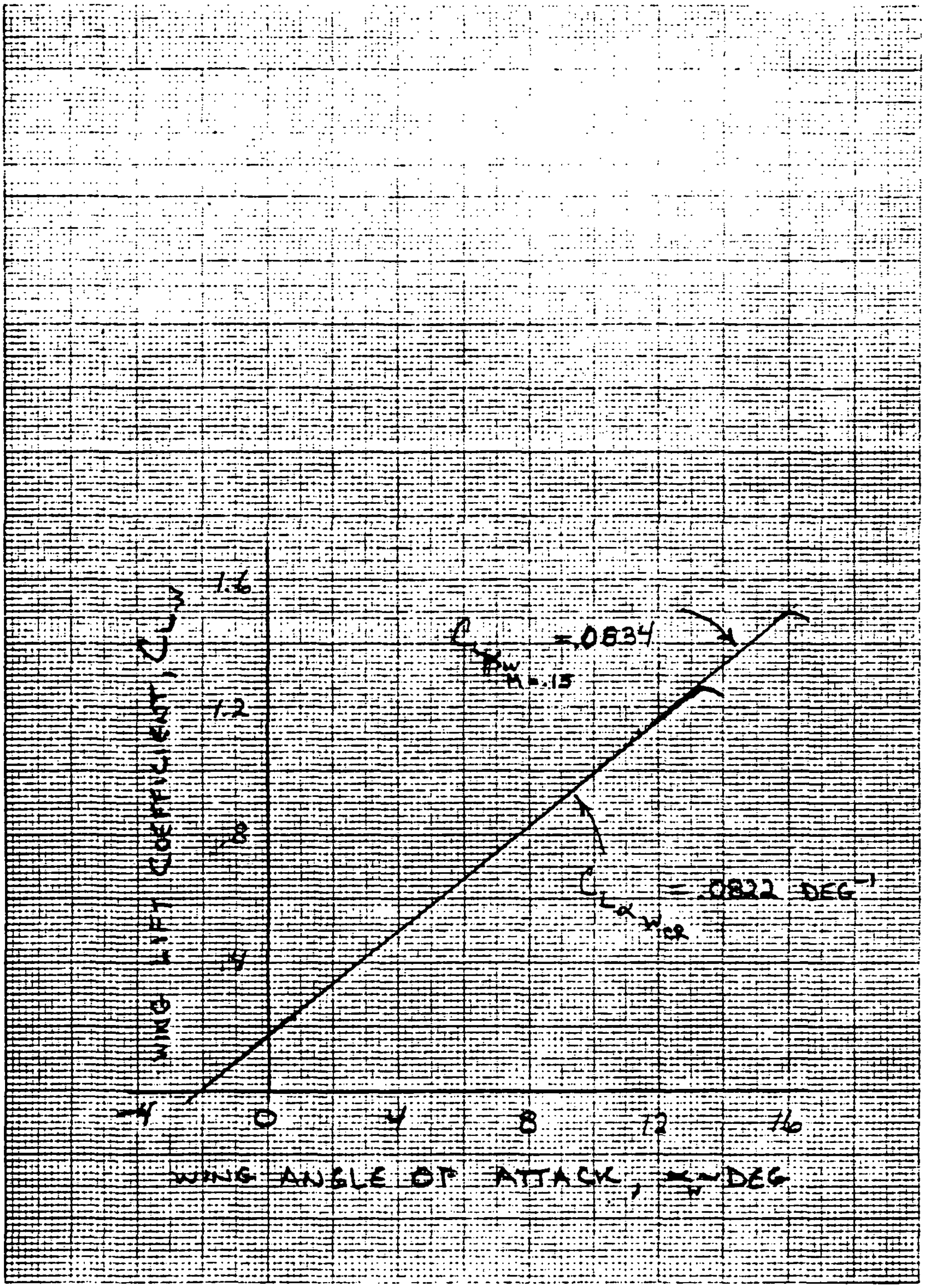

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CALC	12-4-86	TRC			FIGURE 4.3 25, 36, 50 PASSENGER WING LIFT CURVE
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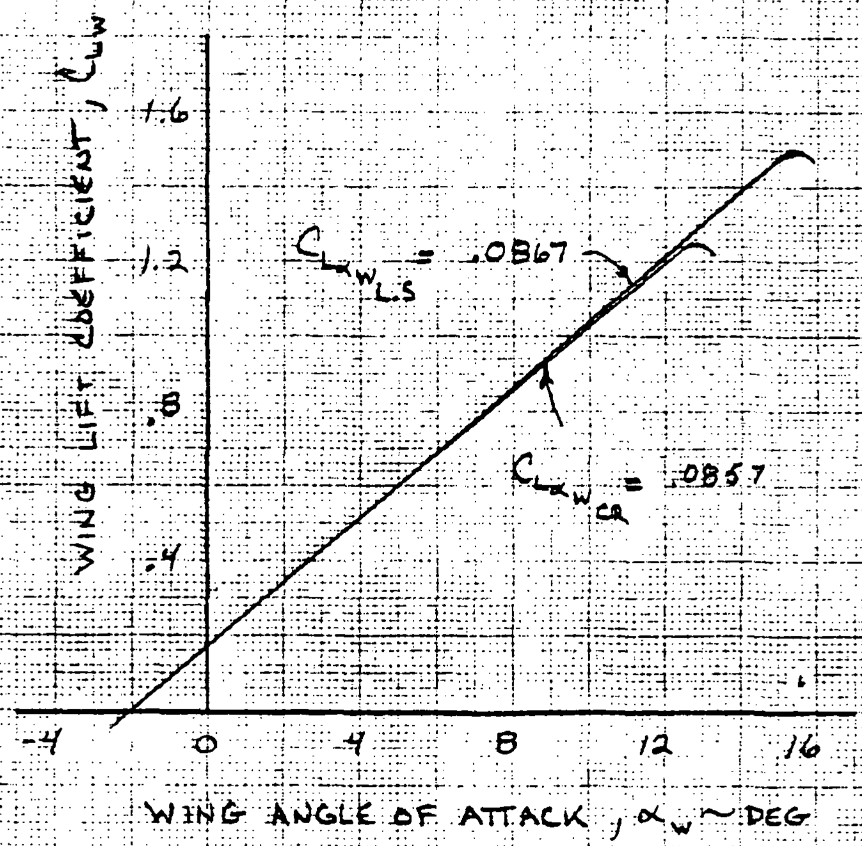

CALC	3-31-87	TRC	REVISED	DATE	FIGURE 4.4 75, 100 PASSENGER WING LIFT CURVE	
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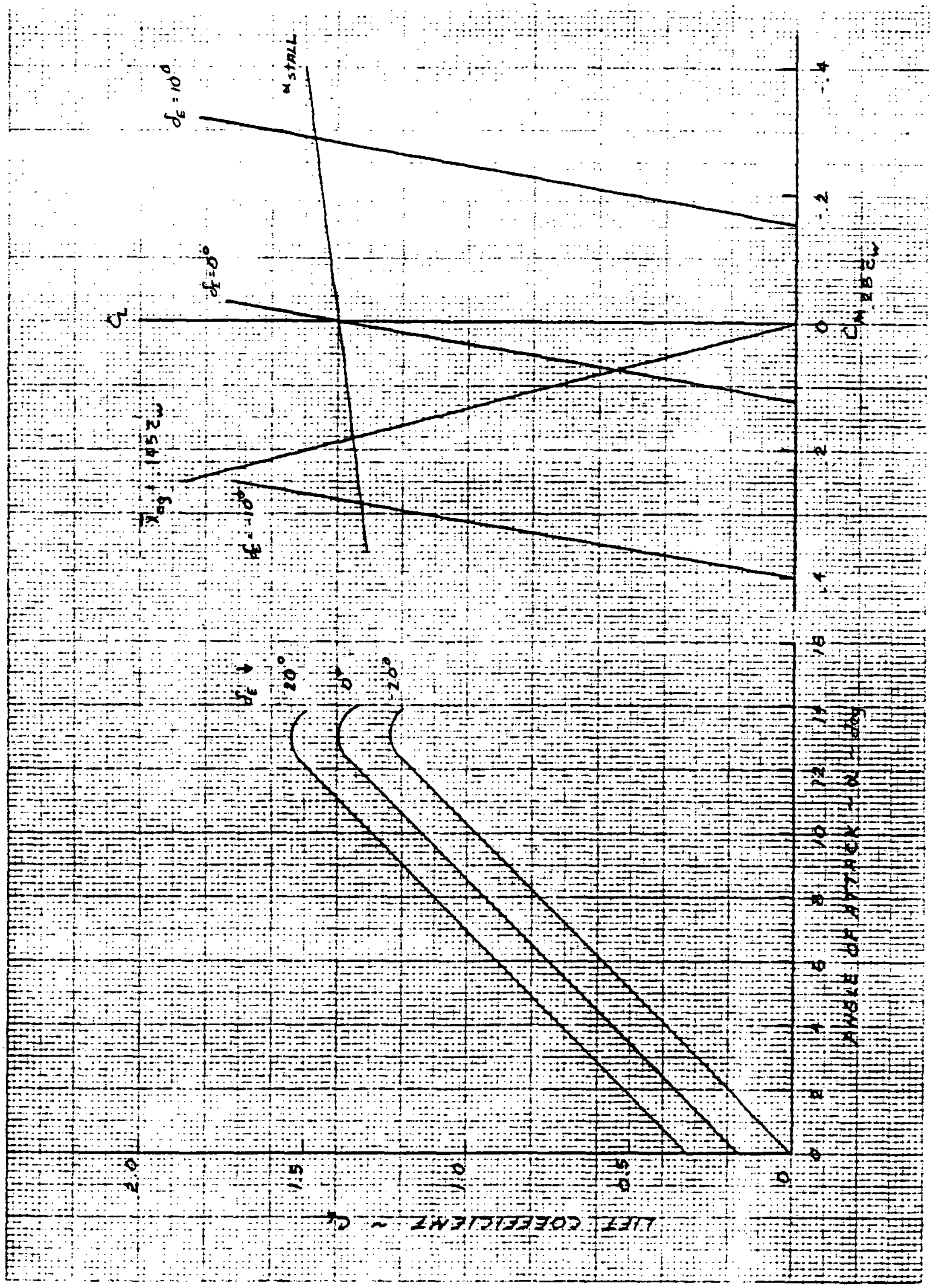

FIGURE 4.5

CALC			REVISED	DATE	25 PASSENGER AIPPLANE CRUISE PITCH - TRIM DIAGRAM	
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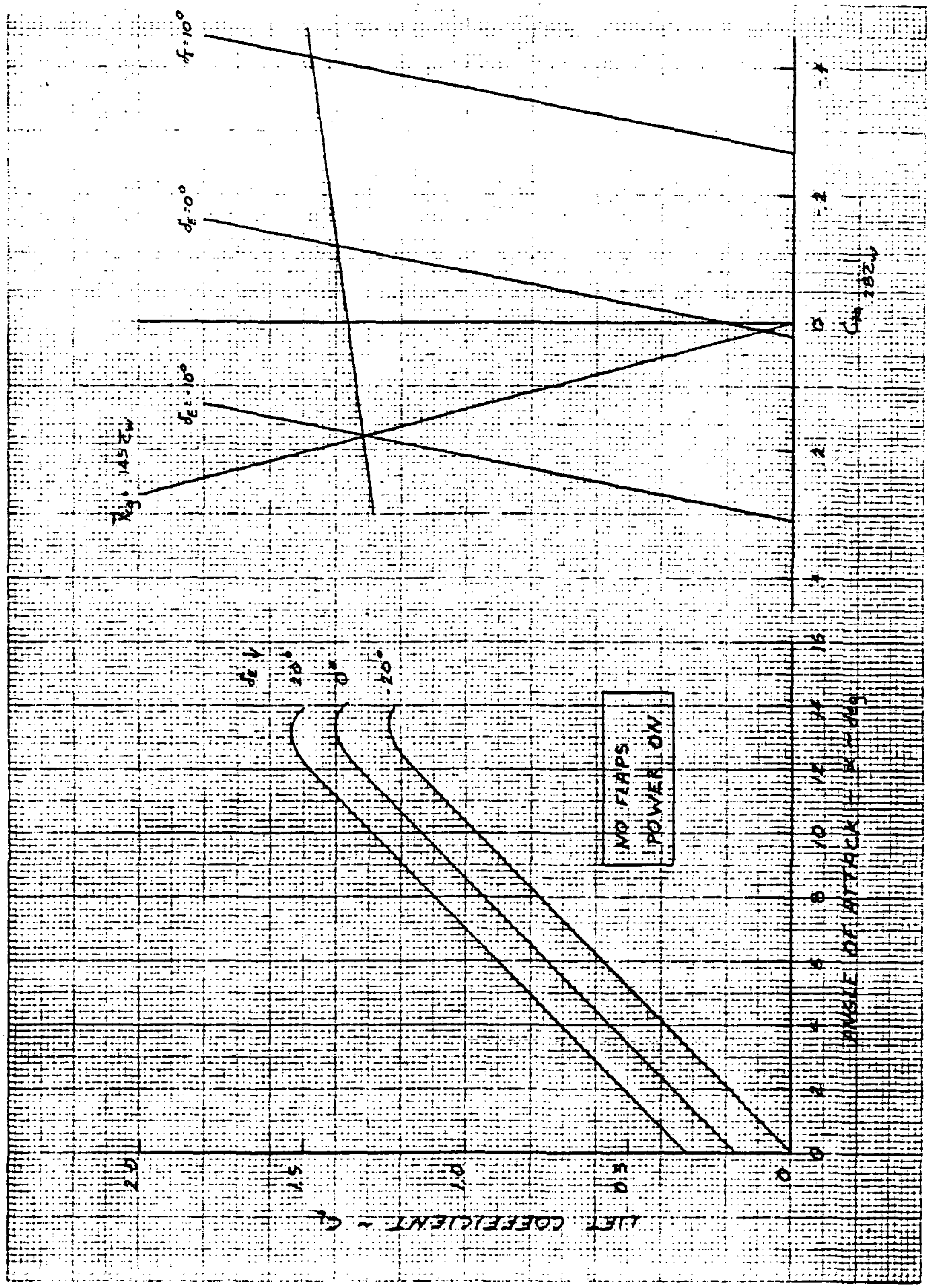

FIGURE 46

CALC			REVISED	DATE	25 PASSENGER AIRPLANE
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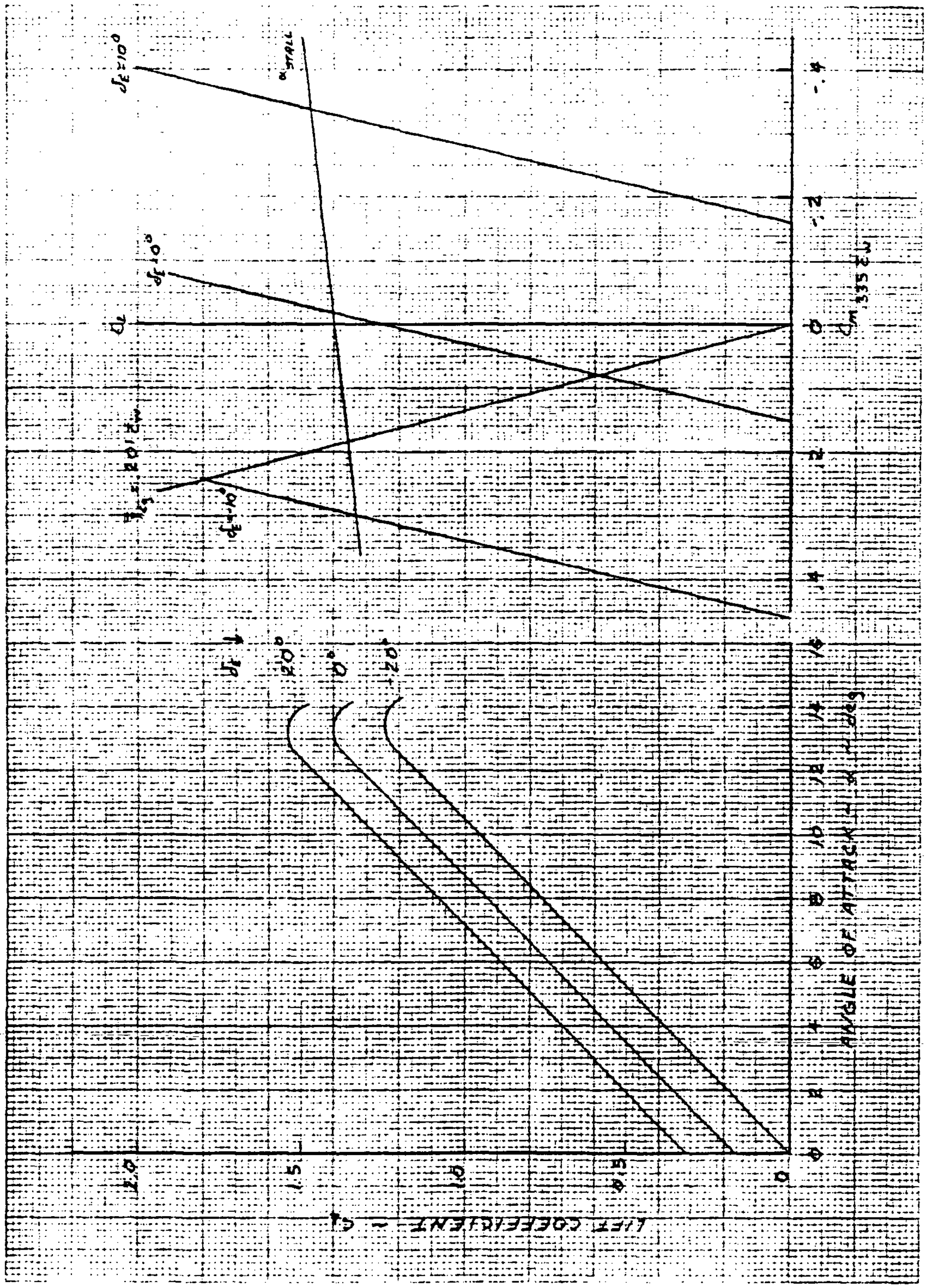

FIGURE 4.7

CALC			REVISED	DATE	36 PASSENGER AIRPLANE CRUISE PITCH-TRIM DIAGRAM	
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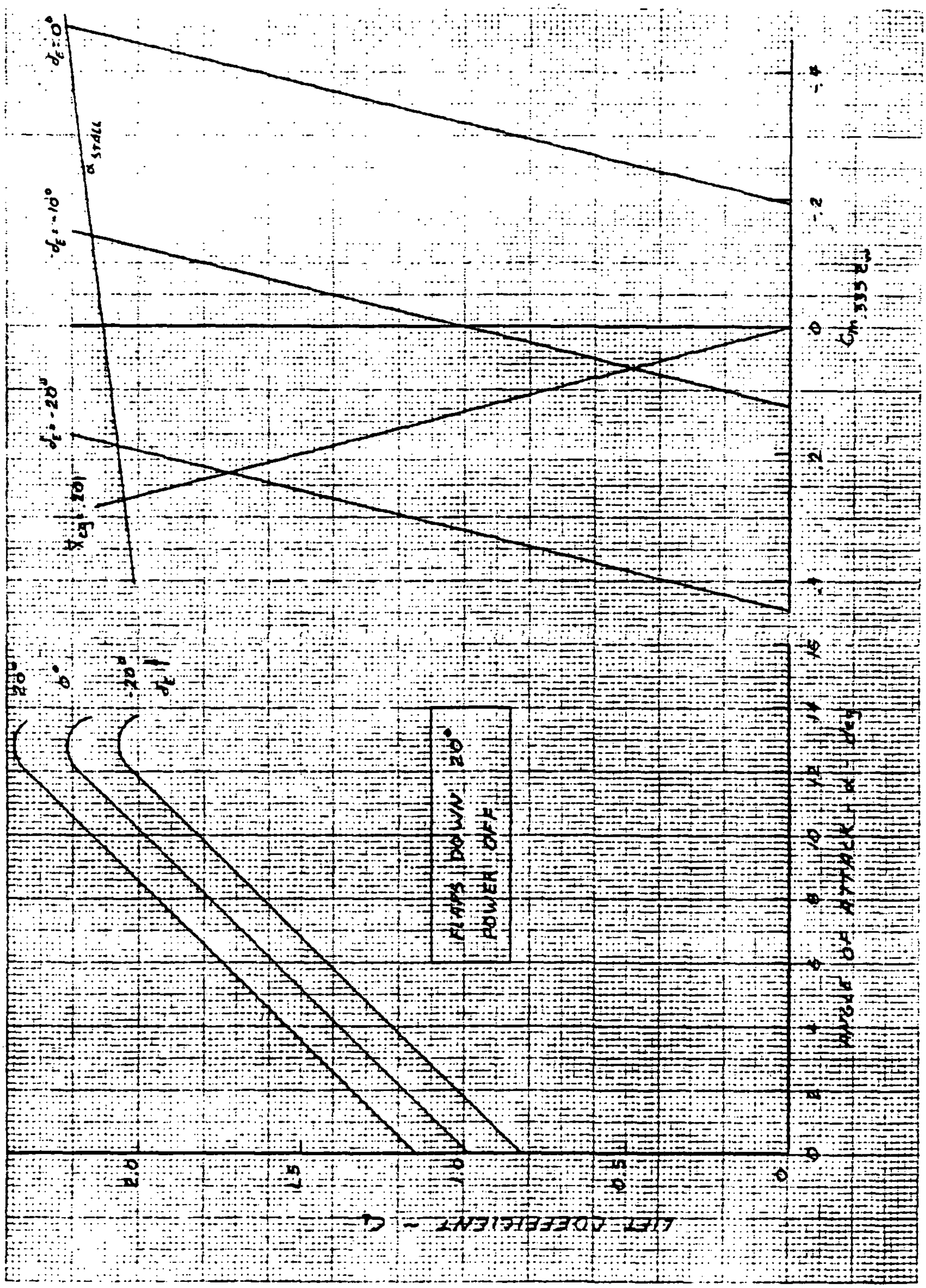

FIGURE 4.8

CALC			REVISED	DATE	36 PASSENGER ~ APPROACH FLAPS DOWN PITCH TRIM DIAGRAM	
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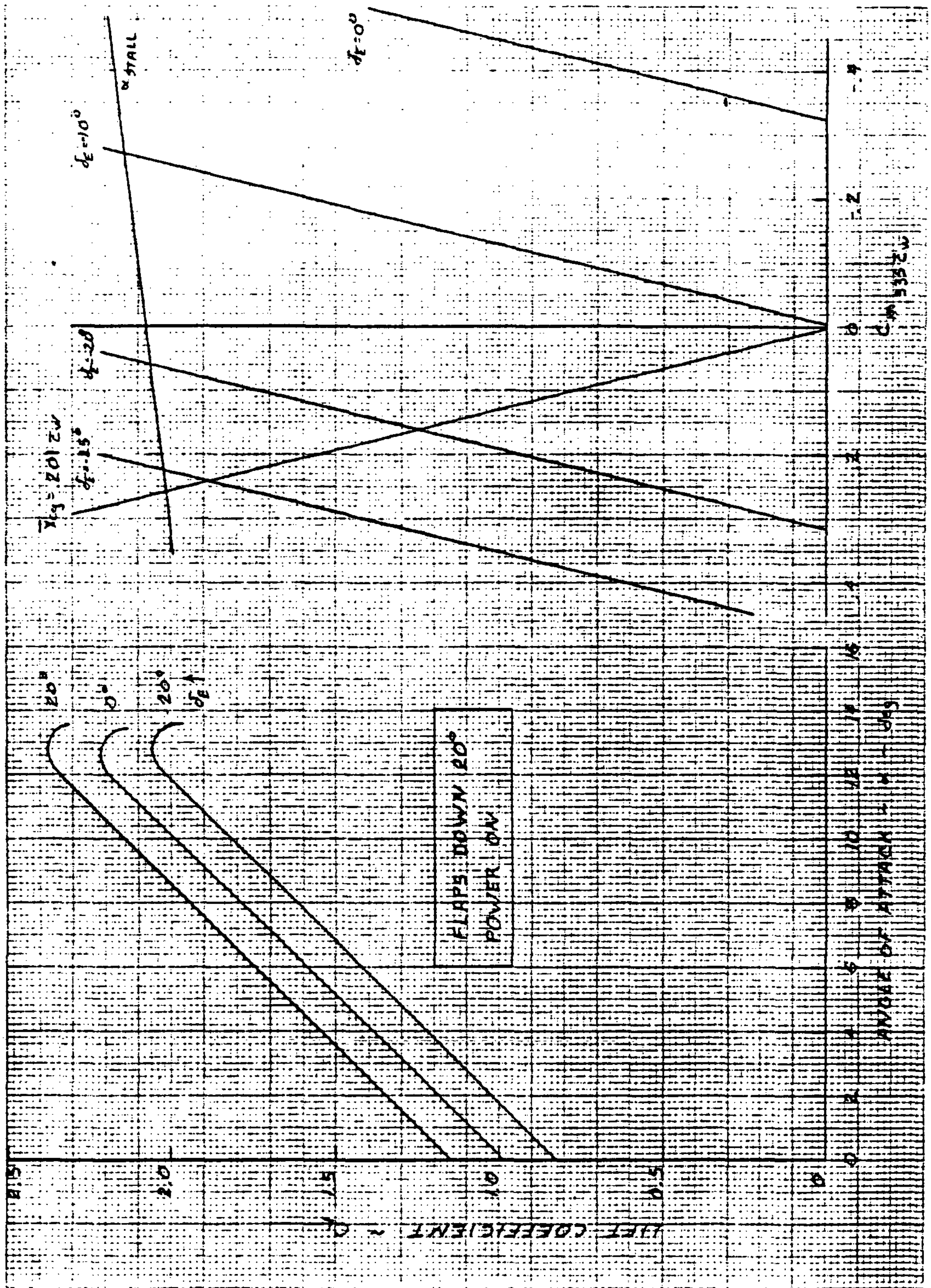

FIGURE 4.9

CALC			REVISED	DATE	36 PASSENGER ~ APPROACH FLAPS DOWN PITCH-TRIM DIAGRAM	
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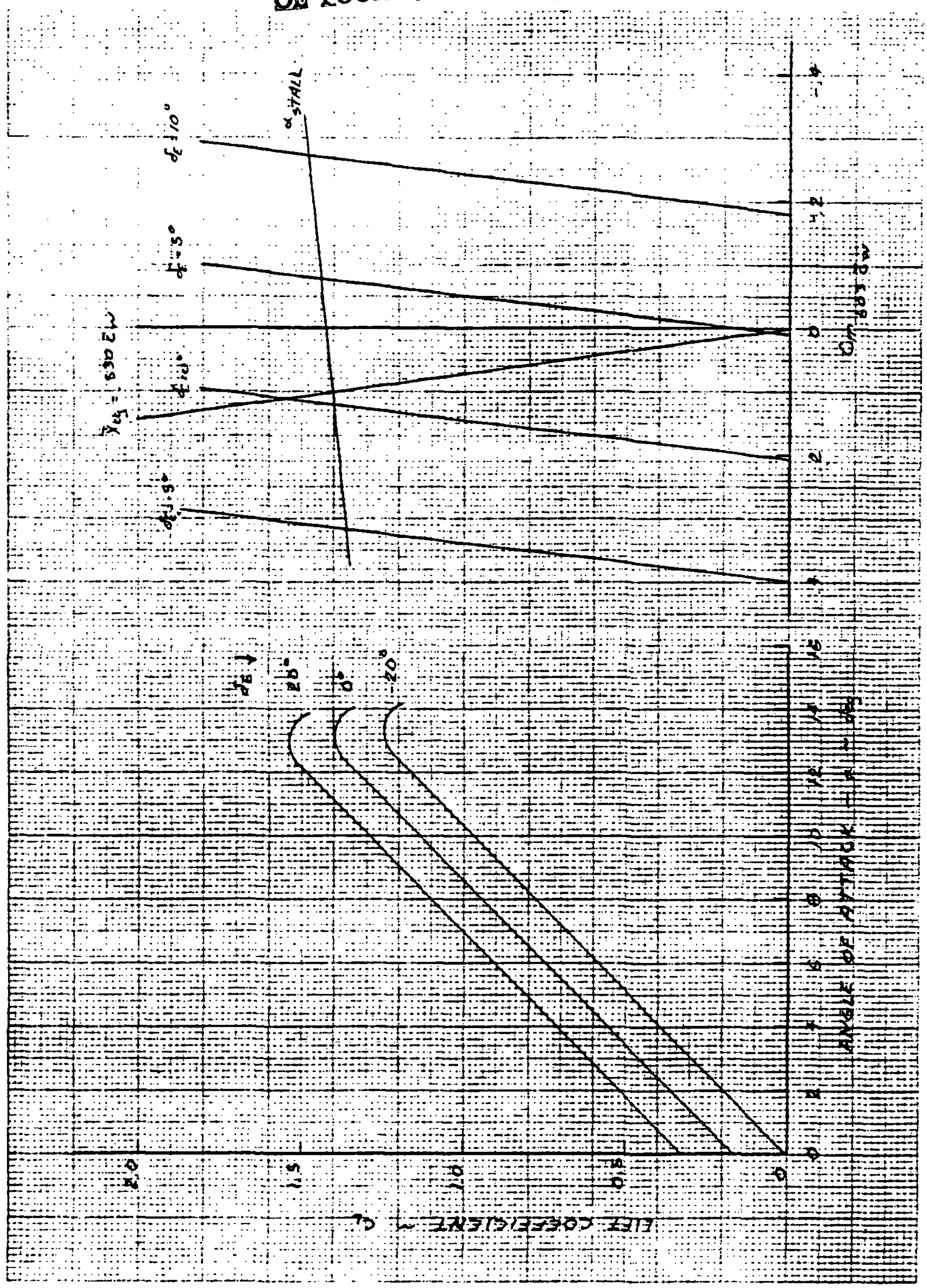

FIGURE 4.10

CALC			REVISED	DATE	50 PASSENGER AIRPLANE CRUISE PITCH-TRIM DIAGRAM	
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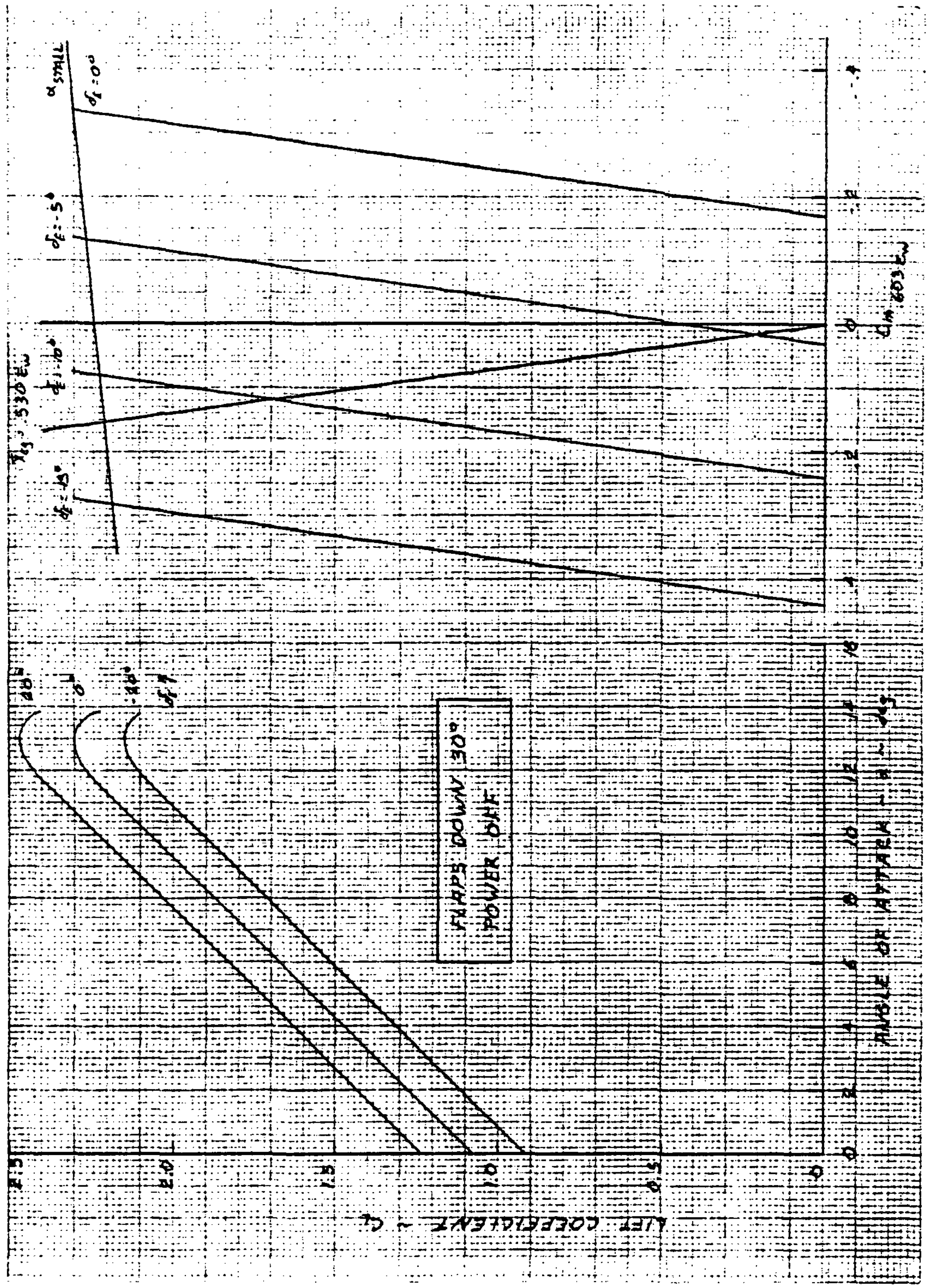

FIGURE 4.11

CALC			REVISED	DATE	50 PASSENGER ~ APPROACH FLAPS DOWN PITCH TRIM DIAGRAM	
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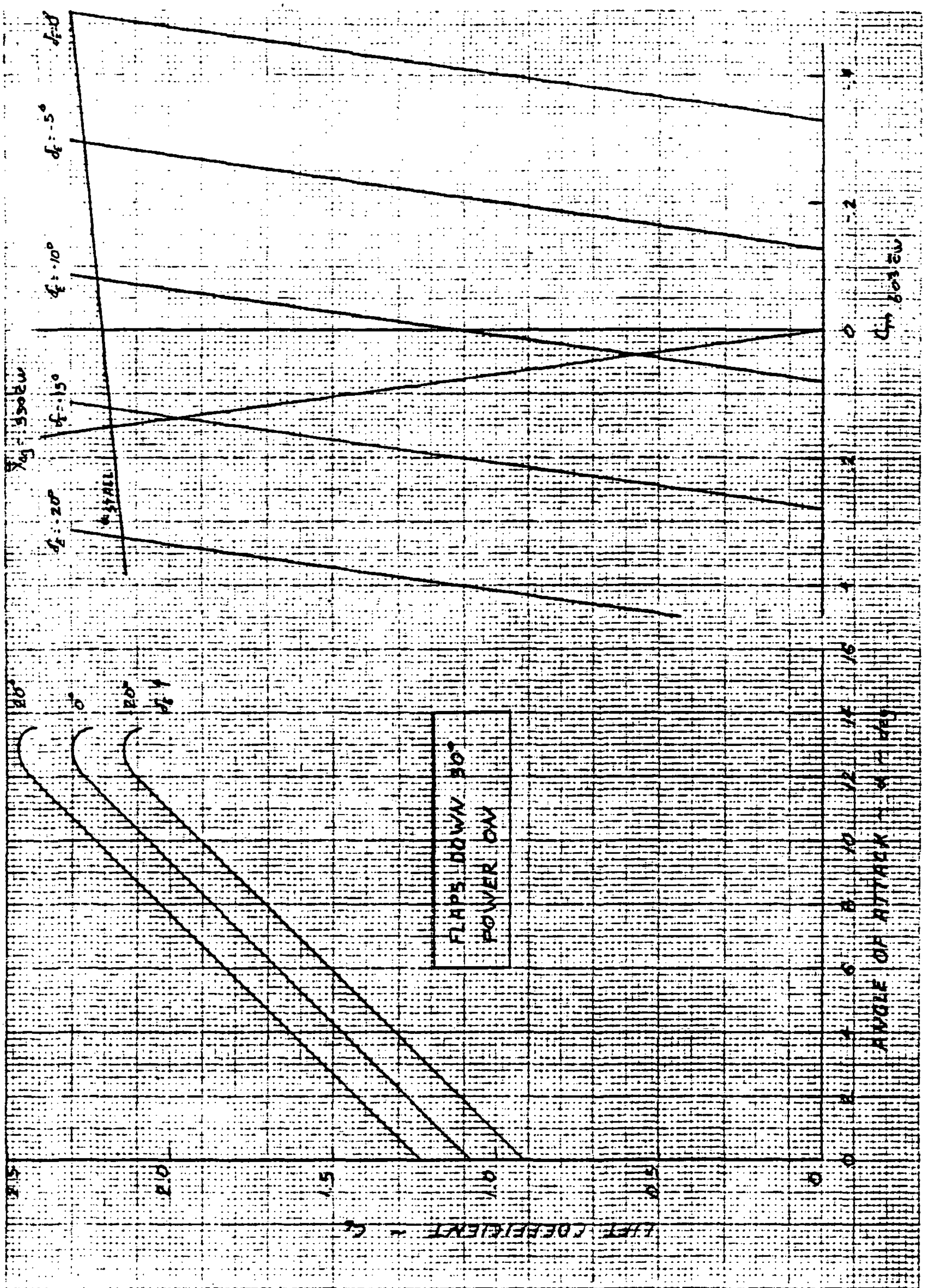

FIGURE 4.12

CALC			REVISED	DATE	50 PASSENGER ~ APPROACH	
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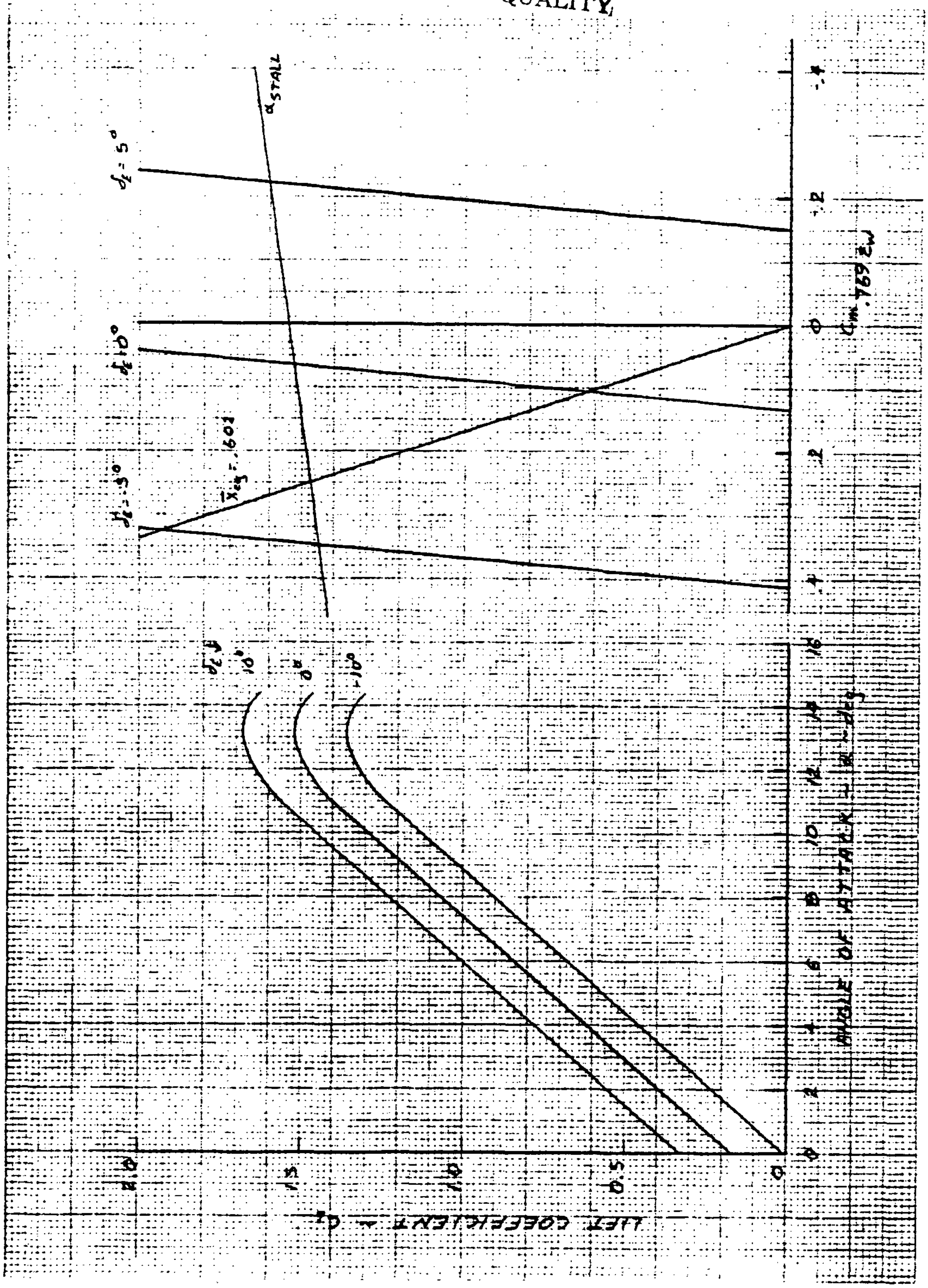

FIGURE 4.13

CALC			REVISED	DATE	75 PASSENGER AIRPLANE CRUISE PITCH-TRIM DIAGRAM	
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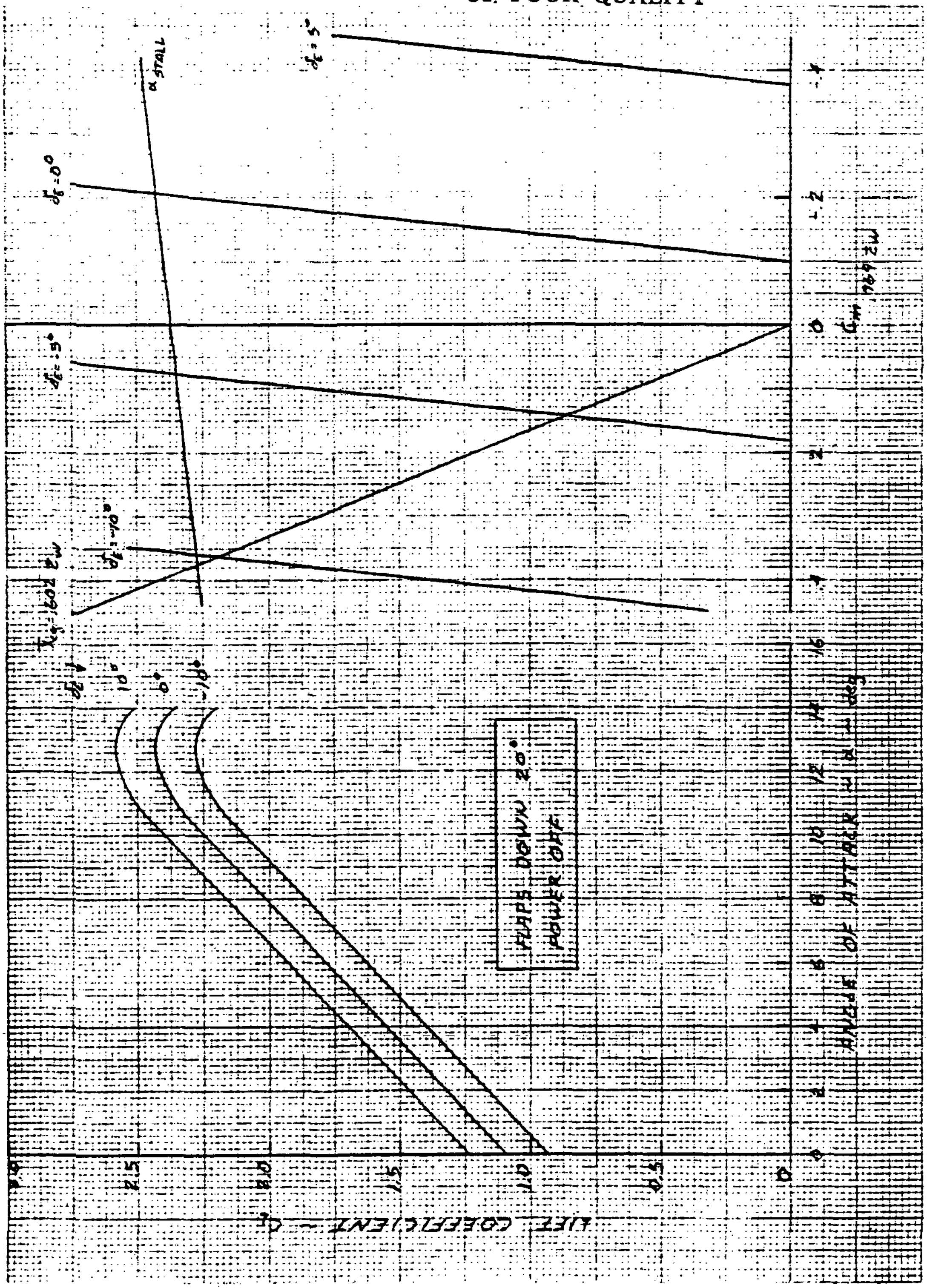

FIGURE 4.14

CALC			REVISED	DATE	75 PASSENGER - APPROACH FLAPS DOWN PITCH TRIM DIAGRAM	
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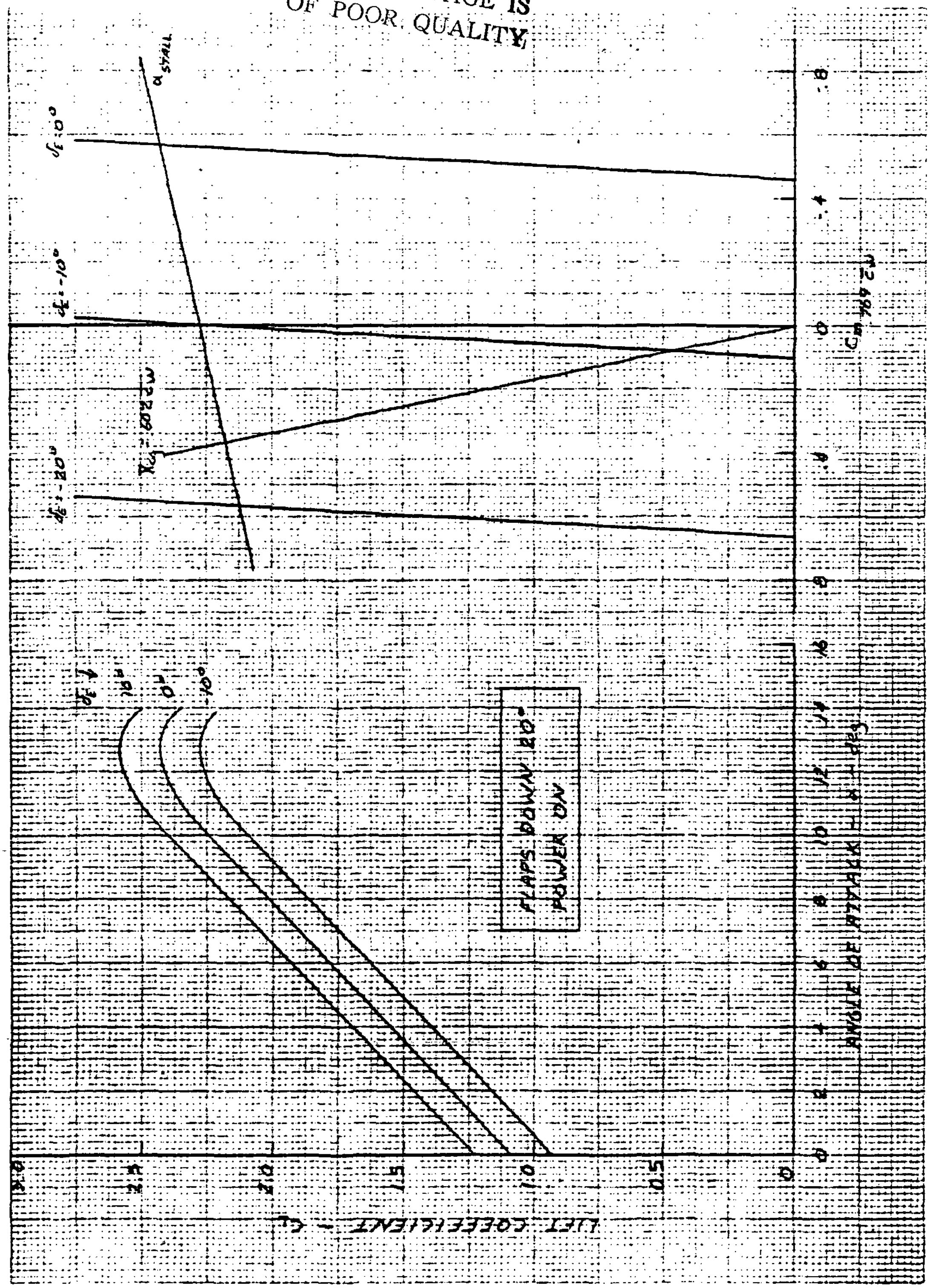

Figure 4.15

CALC			REVISED	DATE	75 PASSENGER - APPROACH FLAPS DOWN PITCH TRIM DIAGRAM	
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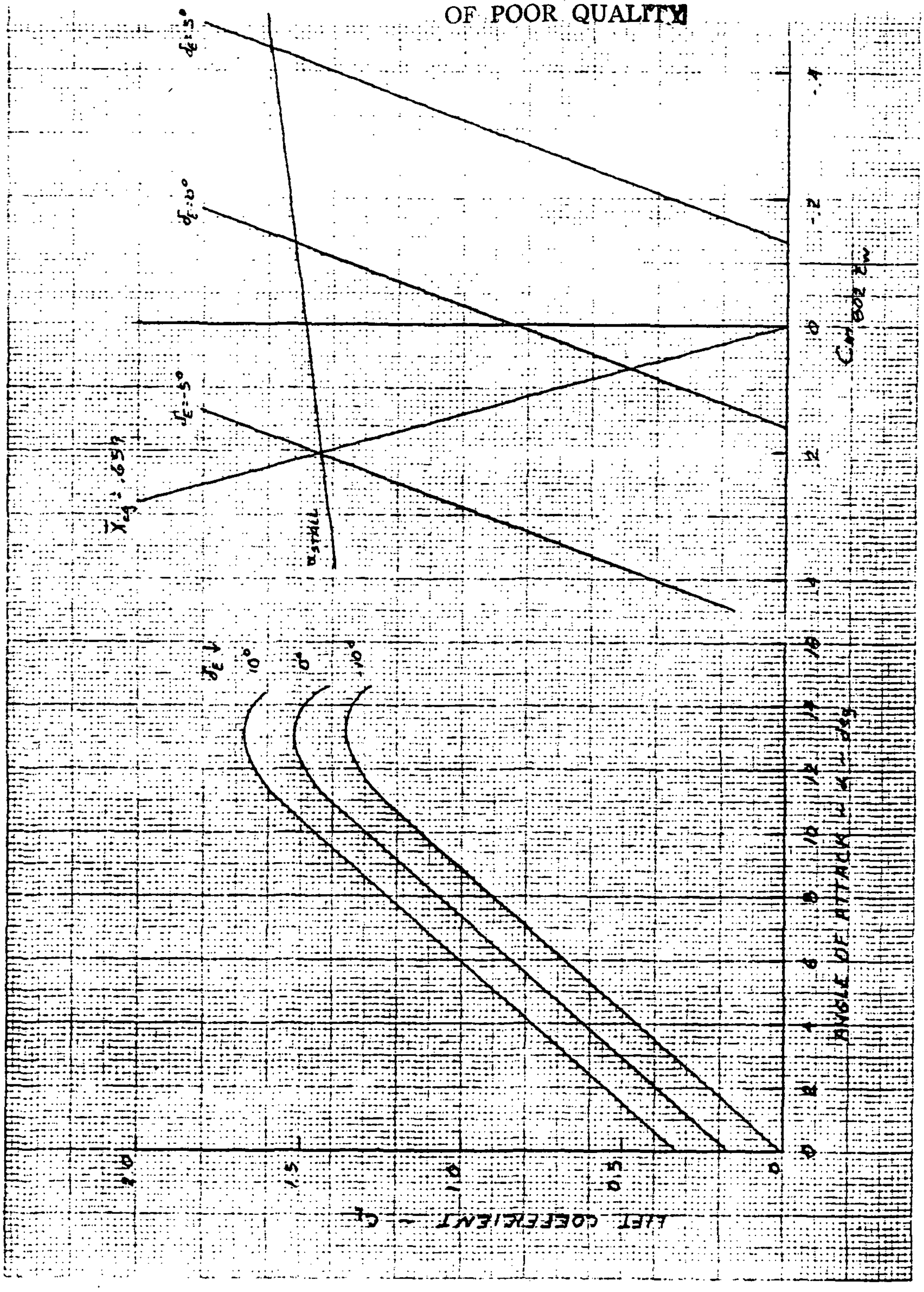

FIGURE 4.16

CALC			REVISED	DATE	100 PASSENGER AIRPLANE CRUISE PITCH-TRIM DIAGRAM	
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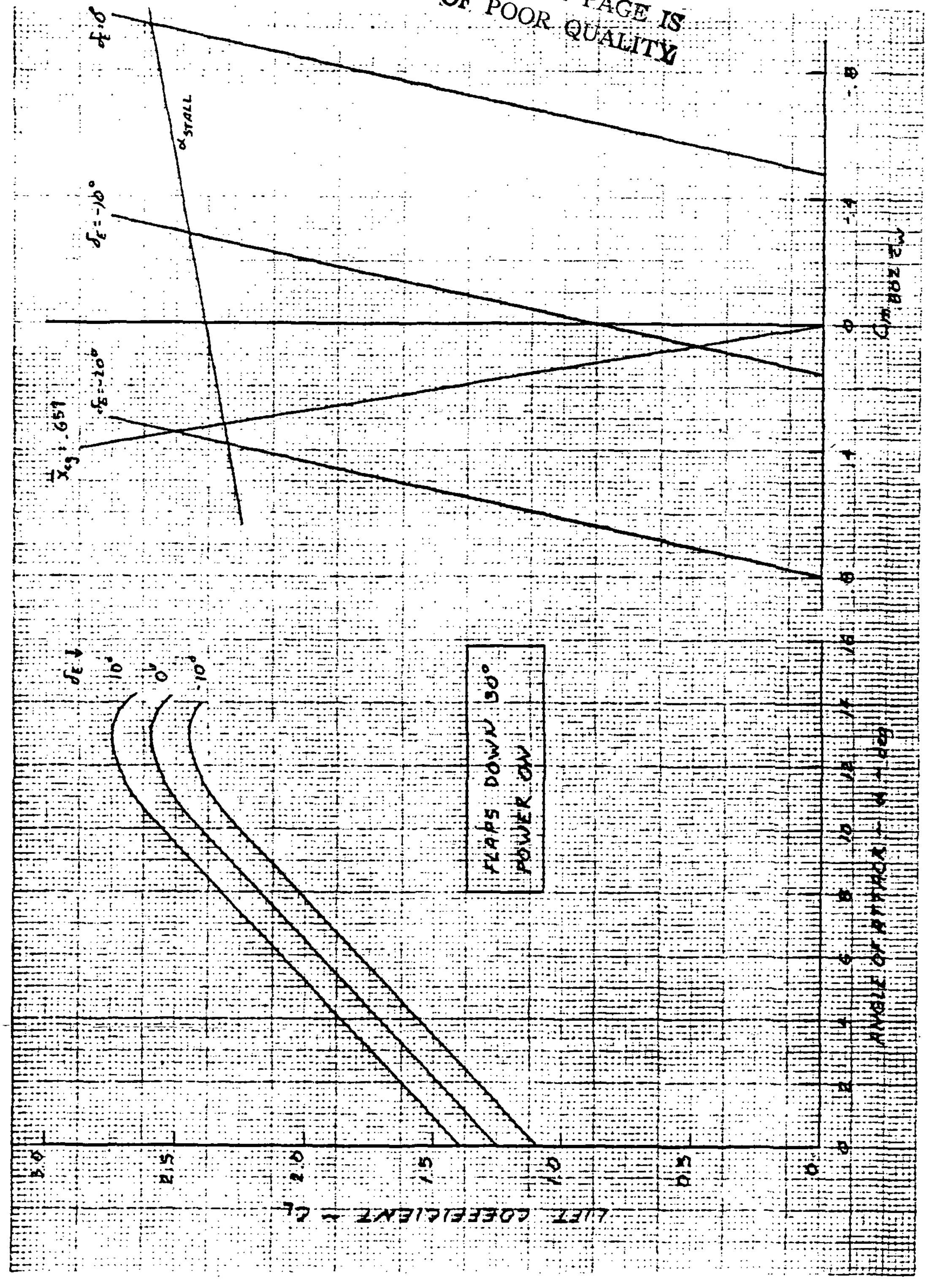

Figure 4.17

CALC			REVISED	DATE	100 PASSENGER - APPROACH	
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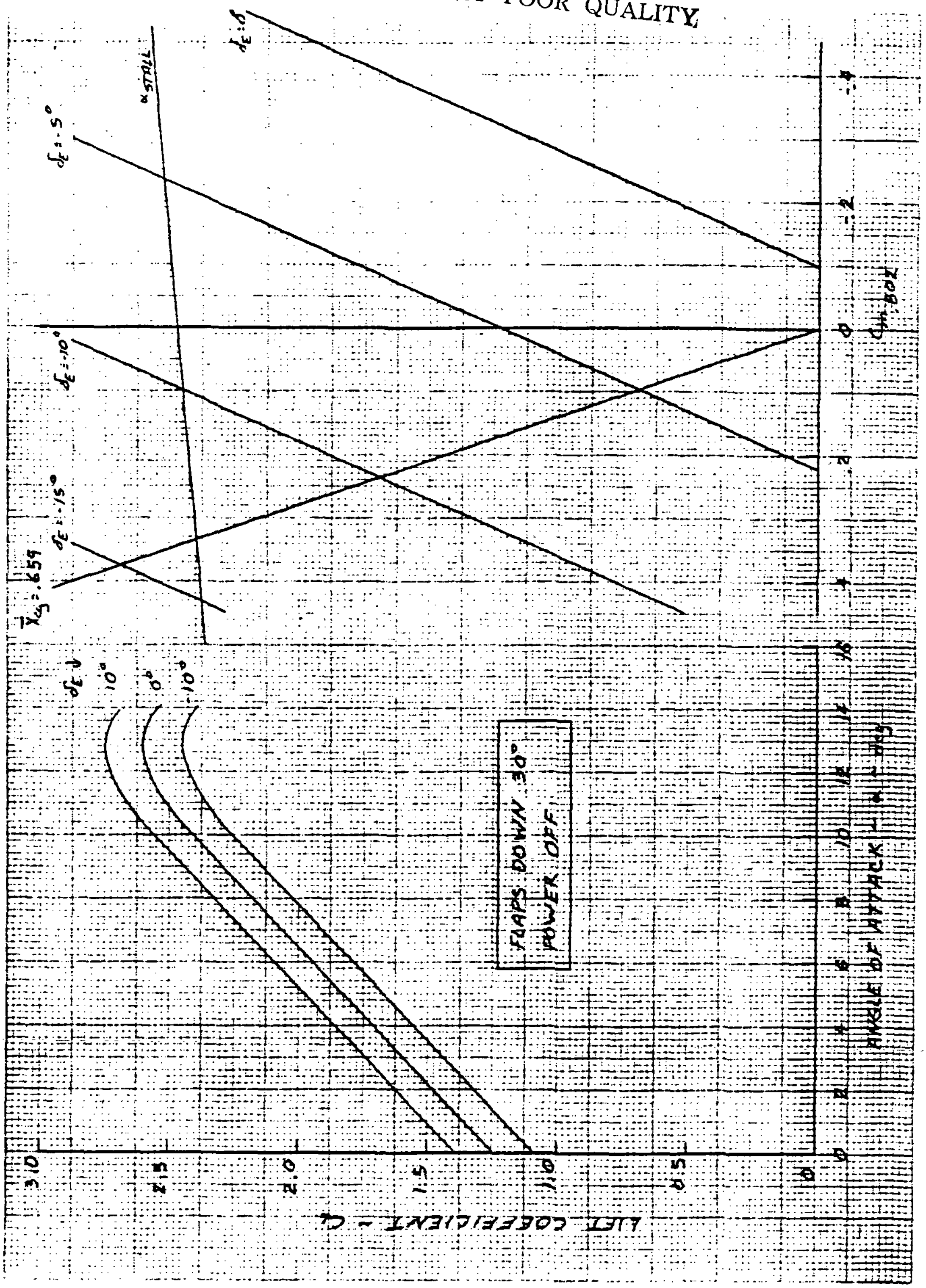

FIGURE 4.18

CALC			REVISED	DATE	100 PASSENGER - APPROACH
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4.5 Handling Qualities

To estimate the handling qualities, the following stability parameters were calculated:

Short Period Frequency
Short Period Damping Ratio
Dutch Roll Frequency
Dutch Roll Damping

These parameters were calculated for cruise and approach at forward and aft C.G. locations. The open loop characteristics are listed in Table 4.6. A further discussion of the handling qualities of the commuter family is contained in Reference 6. None of the airplanes are below class 2 handling qualities. With the exceptions listed below, all meet class 1 handling qualities.

1) 50 passenger, level 2 short period frequency at aft C.G.
2) Twin-bodies (75 and 100), level 2 for dutch roll requirement ($\omega_{N_D} \times \zeta_D$) at forward C.G.

Table 4.6 - Handling Qualities for the Commuter Family

Airplane	Flight Condition C.G. Location	Level Satisfied $\omega_{n_{sp}}$	ζ_{sp}	ω_{n_D}	ζ_D	$\omega_{n_D}\zeta_D$
	fwd C.G. - Cruise	1	1	1	1	1
25 pax	aft C.G. - Cruise	1	1	1	1	1
	fwd C.G. - Approach	1	1	1	1	1
	aft C.G. - Approach	1	1	1	1	1
	fwd C.G. - Cruise	1	1	1	1	1
36 pax	aft C.G. - Cruise	1	1	1	1	1
	fwd C.G. - Approach	1	1	1	1	1
	aft C.G. - Approach	1	1	1	1	1
	fwd C.G. - Cruise	1	1	1	1	1
50 pax	aft C.G. - Cruise	2	1	1	1	1
	fwd C.G. - Approach	1	1	1	1	1
	aft C.G. - Approach	2	1	1	1	1
	fwd C.G. - Cruise	1	1	1	1	2
75 pax	aft C.G. - Cruise	1	1	1	1	1
	fwd C.G. - Approach	1	1	1	1	2
	aft C.G. - Approach	1	1	1	1	1
	fwd C.G. - Cruise	1	1	1	1	2
100 pax	aft C.G. - Cruise	1	1	1	1	1
	fwd C.G. - Approach	1	1	1	1	2
	aft C.G. - Approach	1	1	1	1	1

4.6 Take-off Rotation Requirements

Using the method of Reference 10, the elevator deflection required for take-off have been calculated. The results of this analysis are listed in Table 4.6. All airplanes in the commuter family were able to staisfy take-off rotation requirements.

Table 4.6 - Take-off Rotation Requirements

25 passenger:	δ_E = 16.4 deg
36 passenger:	δ_E = 14.7 deg
50 passenger:	δ_E = 6.2 deg
75 passenger:	δ_E = 3.2 deg
100 passenger:	δ_E = 2.1 deg

4.7 Engine-out Requirements

The engine-out requirements have been checked using a one dimensional model, outlined in Reference 10. The FAR's allow 5° of bank into the operating engine, which eases the required rudder deflections. The engine-out calculations assumed full thrust from the operating engine at V_{MC}. The available thrust and required rudder deflections are listd in Table 4.7

Table 4.7 - Engine-out Requirements

Airplane	Total T-O Thrust	Required δ_R
25 passenger	13,325 lbs	23.1 deg
36 passenger	15,481 lbs	22.9 deg
50 passenger	18,929 lbs	20.5 deg
75 passenger	37,891 lbs	28.1 deg
100 passenger	37,891 lbs	22.4 deg

4.8 Roll Performance

The roll performance of the commuter family was checked using the rolling approximation method of Reference 10.

All members of the family meet level 1 handling qualities requirements. Table 4.8 verifies this. Due to the large increase in Ixx the twinbody configurations have a larger roll time constant. Therefore these configurations have slower roll characteristics.

A roll damper could be designed for the twinbody configurations that could yield similar roll response with the single body configurations.

A seperate surface aileron could be used to achieve this. Seperate surface stability augmentation to achieve common dynamic handling is the subject of Reference 6.

Appendix D contains the engineering calculations for this chapter. A spreadsheet was used to extend the analysis quickly for all 5 airplanes.

Table 4.8 - Summary of Roll Performance

Model	25 pax	36 pax	50 pax	75 pax	100 pax
C_{l_p}	-.715	-.715	-.715	-.792	-.792
$C_{l_{\delta_A}}$	.553	.553	.553	.608	.608
$T_{R_{CR}}$	.22	.27	.30	.53	.65
$T_{R_{Vmc}}$	.34	.41	.47	.84	1.02
$T_{R_{REQ}}$	1.4	1.4	1.4	1.4	1.4
ϕ^*_{CR}	107°	104°	102°	56°	52°
$\delta_{A_{CR}}$	5°	5°	5°	5°	5°
ϕ^*_{Vmc}	56°	53°	52°	35°	31°
$\delta_{A_{Vmc}}$	10°	10°	10°	10°	10°

ϕ^*_{CR} = Roll angle in 1.9 seconds, must be at least 45°

ϕ^*_{Vmc} = Roll angle in 1.8 seconds, must be at least 30°

4.8.1 Lateral Acceleration of the Twinbody Configurations

The lateral acceleration of the twinbody models is of concern for reasons of comfort to the passengers and how this motion will affect the pilot.

Lateral acceleration was calculated by:

$$\dot{p} = L_{\delta_A} \delta_A e^{L_p t}$$

and $a_y = \dot{p}\, l$

where l = Distance from airplane centerline to fuselage centerline.

The following table summarizes the accelerations for the twinbody models.

Table 4.9 - Lateral Accerations For the Twinbody Models

	75 pax		100 pax	
	Fwd C.G.	Aft C.G.	Fwd C.G.	Aft C.G.
$\dot{p}_{CR}$ (rad/sec^2)	.037	.004	.058	.009
$\dot{p}_{Vmc}$ (rad/sec^2)	.080	.027	.096	.040
l (ft)	24.08	24.08	24.08	24.08
$a_{y_{CR}}$ (ft/sec^2)	.900	.099	1.395	.212
$a_{y_{Vmc}}$ (ft/sec^2)	1.936	.641	2.322	.953
$(\frac{a_y}{g})_{CR}$	.028	.003	.043	.007
$(\frac{a_y}{g})_{Vmc}$	.060	.020	.072	.030

The accelerations at the aft loading conditions (highest Ixx) appear acceptable in terms of good handling qualities when compared with data in Reference 11.

At forward C.G. locations the accelerations are large. The rolling mode of the twinbody configuration will need to be augmented to be similiar to the single bodies.

Common roll mode time constants across the family should be the objective of roll control commonality. This could easily be implemented using digital compensation.

5.0 Stick Forces and Gradients

The purpose of this chapter is to present the stick forces and stick gradients that affect the pilot.

It will be desirable to augment the stick forces and gradients so that these parameters are similiar for each airplane in the family.

Commonality will be attempted by using a programmable control loader. This system can saugment stick forces in the range of 5 to 65 lbs/in. Therefore, all pilot stick forces required must lie in the range of 5 to 65 lbs/in. Commonalizing stick force gradients presents some design problems. This will be discussed in detail in section 5.5. Stick force and gradient calculations are contained in Appendix F. These calculations were completed using a spreadsheet.

5.1 Control Surface Hinge Moments

The control surface hinge moments were calculated using Reference 12. The hinge moments for the commuter family are contained in Tables 5.1 to 5.3.

Table 5.1 - Elevator Hinge Moments

Model	25 pax	36 pax	50 pax	75 pax	100 pax
c_f/c	.35	.35	.35	.35	.35
S_E	42 ft²	42 ft²	42 ft²	143 ft²	143 ft²
c_f	1.64 ft	1.64 ft	1.64 ft	1.64 ft	1.64 ft
C_{h_α}	-.323	-.323	-.323	-.241	-.241
$C_{h_{\delta_E}}$	-.177	-.177	-.177	-.422	-.422

Table 5.2 - Rudder Hinge Moments

Model	25 pax	36 pax	50 pax	75 pax	100 pax
c_f/c	.35	.35	.35	.35	.35
S_R	60 ft²	60 ft²	60 ft²	119 ft²	119 ft²
c_f	4.20 ft	4.20 ft	4.20 ft	4.20 ft	4.20 ft
C_{h_β}	-.043	-.043	-.043	-.086	-.086
$C_{h_{\delta_R}}$	-.167	-.167	-.167	-.334	-.334

Table 5.3 - Aileron Hinge Moments

Model	25 pax	36 pax	50 pax	75 pax	100 pax
c_f/c	.30	.30	.30	.30	.30
S_A	12 ft^2	12 ft^2	12 ft^2	12 ft^2	12 ft^2
c_f	2.00 ft	2.00 ft	2.00 ft	2.00 ft	2.00 ft
C_{h_α}	-.042	-.042	-.042	-.036	-.036
$C_{h_{\delta_A}}$	-.073	-.073	-.073	-.094	-.094

5.2 Longitudinal Stick Forces and Stick Gradients

Using methods in Reference 10, the stick force, F_s, stick force per G gradient, and the stick force per knot were calculated. Table 5.4 through 5.6 present the results. Flight conditions analyzed:

a) V_{mc} = 207.5 fps, sealevel, fwd and aft C.G.

b) M = 0.7, 30,000 ft, fwd and aft C.G.

It is desired to have longitudinal stick forces less than 60 lbs. The force per knot -.167 lbs/kt or less. The force per G should be between 23 and 80 lbs/G. If the forces and gradients are in these ranges then the FAR 25 specifications will be satisfied.

Table 5.4 - Longitudinal Stick Forces

Model	V_{mc} fwd C.G.	V_{mc} aft C.G.	CR fwd C.G.	CR aft C.G.
25 pax	44	3	176	169
36 pax	1	-38	16	-1
50 pax	-48	-48	-72	-49
75 pax	-170	-570	-570	-2675
100 pax	-126	-201	-567	-573

Stick forces in lbs

Table 5.5 - Longitudinal Stick Force per G

Model	V_{mc} fwd C.G.	V_{mc} aft C.G.	CR fwd C.G.	CR aft C.G.
25 pax	65	13	69	-6
36 pax	47	-1	45	-27
50 pax	18	3	-11	-32
75 pax	152	818	28	426
100 pax	203	65	173	-20

Gradient in lbs/G

Table 5.6 - Longitudinal Stick Force per Knot Gradient

Model	V_{mc} fwd C.G.	V_{mc} aft C.G.	CR fwd C.G.	CR aft C.G.
25 pax	.08	.18	.23	.43
36 pax	-.06	.02	-.02	.14
50 pax	-.07	-.03	-.06	.01
75 pax	-1.09	-5.25	-1.42	-7.81
100 pax	-1.07	-.85	-1.76	-1.38

Gradient in lbs/kt

5.3 Rudder Pedal Forces and Gradients

Tables 5.7 and 5.8 contain rudder pedal forces and rudder pedal force per degree of sideslip. The rudder pedal force should be less than 150 lbs, and the sideslip gradient should be 5 lbs/deg. at Vmc.

Table 5.7 - Rudder Pedal Forces

Model	V_{mc}	Cruise
25 pax	177	166
36 pax	308	910
50 pax	383	1238
75 pax	319	538
100 pax	479	1248

Pedal forces in lbs.

Table 5.8 - Rudder Pedal Gradient

Model	V_{mc}	Cruise
25 pax	35	55
36 pax	62	303
50 pax	76	413
75 pax	64	179
100 pax	96	416

Pedal gradients in lbs/deg of sideslip

5.4 Aileron Wheel Forces

Table 5.9 presents aileron wheel forces required to meet the FAR specifications for roll performance. These forces were acceptable and similiar on all airplanes and were not augmented. The FAR's suggest 5 lbs of force needs to be sustained by the pilot.

Table 5.9 Aileron Wheel Forces

Model	V_{mc}	Cruise
25 pax	-4.0	-6.0
36 pax	-4.0	-6.0
50 pax	-4.0	-6.0
75 pax	-4.6	-6.8
100 pax	-4.6	-6.8

Wheel forces in lbs.

5.5 Stick Force Commonality

It is obvious that the data in Table 5.4 to 5.8 does not meet FAR 25 requirements.

a) Stick and pedal forces are too large.

b) Gradients do not meet FAR requriements, especially at aft C.G.

From the calculations in Appendix F it is determined that all the airplanes in the family have an unstable stick free static margin. This causes the stick force speed gradient to be positive.

A trim tab design was attempted to correct this deficiency. Using the tab remedied the stick force speed gradient but caused the stick force per G gradient to not met FAR requirements.

It was concluded that a trim tab design was not the answer to attaining stick force commonality.

5.5.1 Conclusions

1) As currently balanced, the commuter family will not meet FAR 25 requirements

5.5.2 Recommendations

1) The designers feel that an iteration through the weight and balance, and stability and control calculations may allow for a stable stick force static margin. This could allow for the stick force gradients to meet FAR requirements.

2) The sensitivity of the stick forces due to the control surface hinge moments is dramatic. The hinge moments should be calculated accurately. The horizontal tail uses an inverted NLF airfoil. The C_{h_o} of this surface needs to be investigated.

3) The designers feel confident that a proposal for stick force commonality will be possible if the previous recommendations are followed.

6. CLASS II DRAG PREDICTION

The purpose of this chapter is to determine the class II drag polars for the family of commuter airplanes. The class II method consists of the drag breakdown procedure outlined in Reference 13. In this analysis, the drag polars are computed seperately for the different airplanes (25, 36, 50, 75 and 100 passenger airplanes).

The total airplane drag coefficient is broken down into the following components:

$$C_D = C_{D_{wing}} + C_{D_{fus}} + C_{D_{emp}} + C_{D_{np}} + C_{D_{flaps}} + C_{D_{gear}} + C_{D_{cw}}$$

Laminar flow conditions are accounted for in the determination of the wing and empennage drag. Laminar flow is assumed to extend over 50% of the chord of the wing, horizontal tail and vertical tail. Also, 12.5 ft of laminar flow was considered over the nose cone of the fuselage.

The drag due to the windshield ($C_{D_{cw}}$) was accounted for in the fuselage drag determination.

The pylons were considered as lifting surfaces because of their relatively large areas, and a lift coefficient due to pylons (C_{L_p}) was accounted for.

In the case of the nacelle, an interference drag element ($C_{D_{n_{int}}}$) was determined, it has been accounted for in the C_{D_n} calculations.

For the landing gear drag estimation, only low speed conditions were applied (approach at M=0.19).

Appendix G contains the engineering calculations for this chapter. Table 6.1 contains the drag polars for the family of commuter airplanes. Table 6.2 summarizes the NLF assumptions used in the drag analysis. Figures 6.1 to 6.10 present the drag polars for the family of commuter airplanes. By comparing the class II and class I drag polars, note that the difference doesn't exceed 5%. This reinforces the fact that the class I drag polar estimation is fairly reliable.

Table 6.1 - Drag Polar Equations

Airplane	L/D_{max}	Cruise	Low Speed (0° flaps) (gear down)	Low Speed (30° flaps) (gear down)
25	24.4	$.0129 + .0309\ C_L^2$	$.1242 + .0308\ C_L^2$	$.1613 + .0303\ C_L^2$
36	22.4	$.0160 + .0309\ C_L^2$	$.1319 + .0308\ C_L^2$	$.1690 + .0308\ C_L^2$
50	22.6	$.0156 + .0309\ C_L^2$	$.1658 + .0308\ C_L^2$	$.2029 + .0308\ C_L^2$
75	26.6	$.0139 + .0253\ C_L^2$	$.1564 + .0240\ C_L^2$	$.2224 + .0240\ C_L^2$
100	26.2	$.0145 + .0253\ C_L^2$	$.1857 + .0240\ C_L^2$	$.2517 + .0204\ C_L^2$

Table 6.2 - Natural Laminar Flow Assumptions

Wing	50% chord, on all airplanes
Fuselage	12.5 ft from the nose, for all airplanes
Horizontal Tail	50% chord, on all airplanes
Vertical Tail	50% chord, on all airplanes

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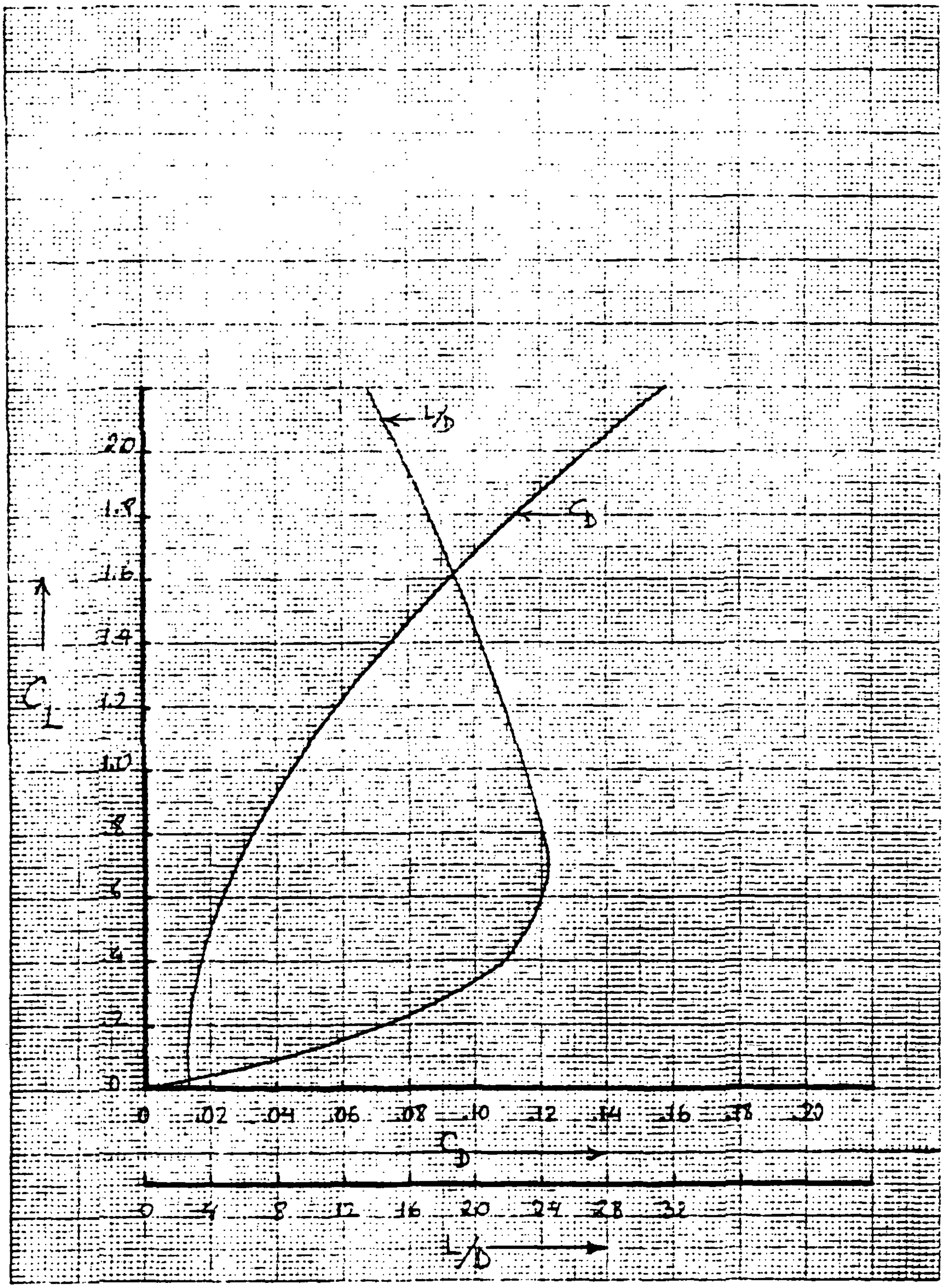

CALC			REVISED	DATE	Figure 6.1 25 Passenger Cruise Drag Polar	
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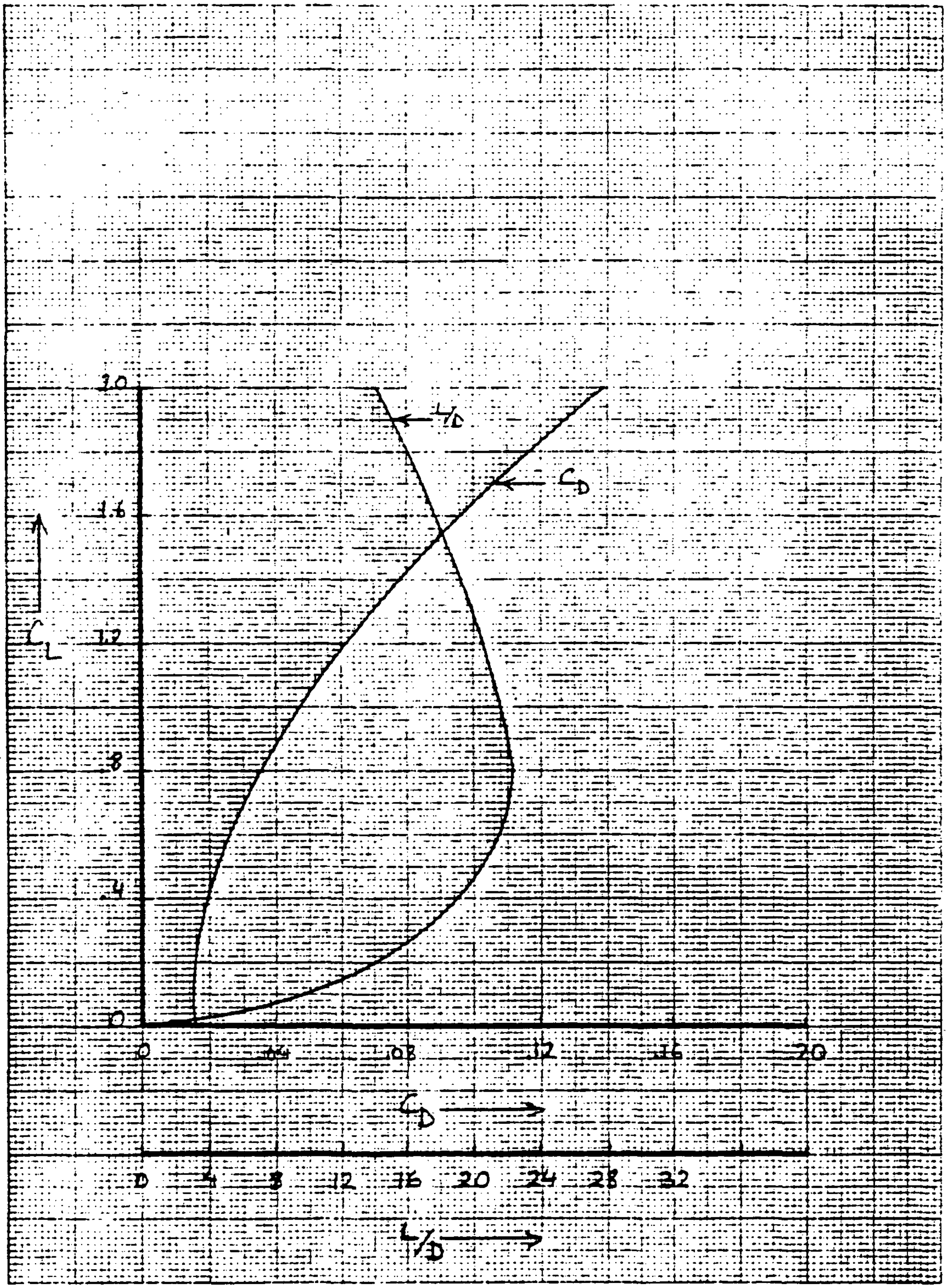

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Figure 6.2 36 Passenger Cruise Drag Polar

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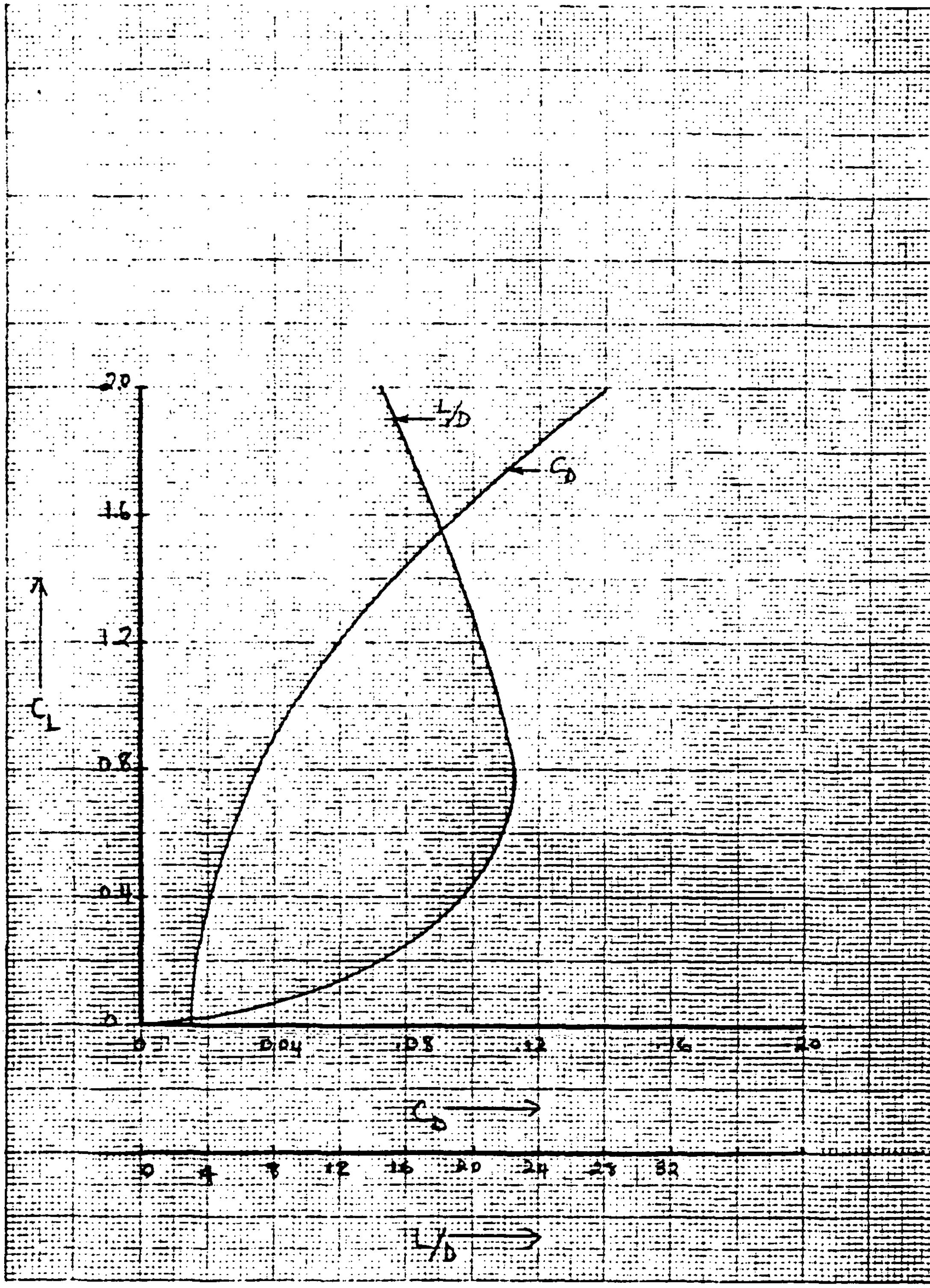

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Figure 6.3 50 Passenger Cruise Drag Polar

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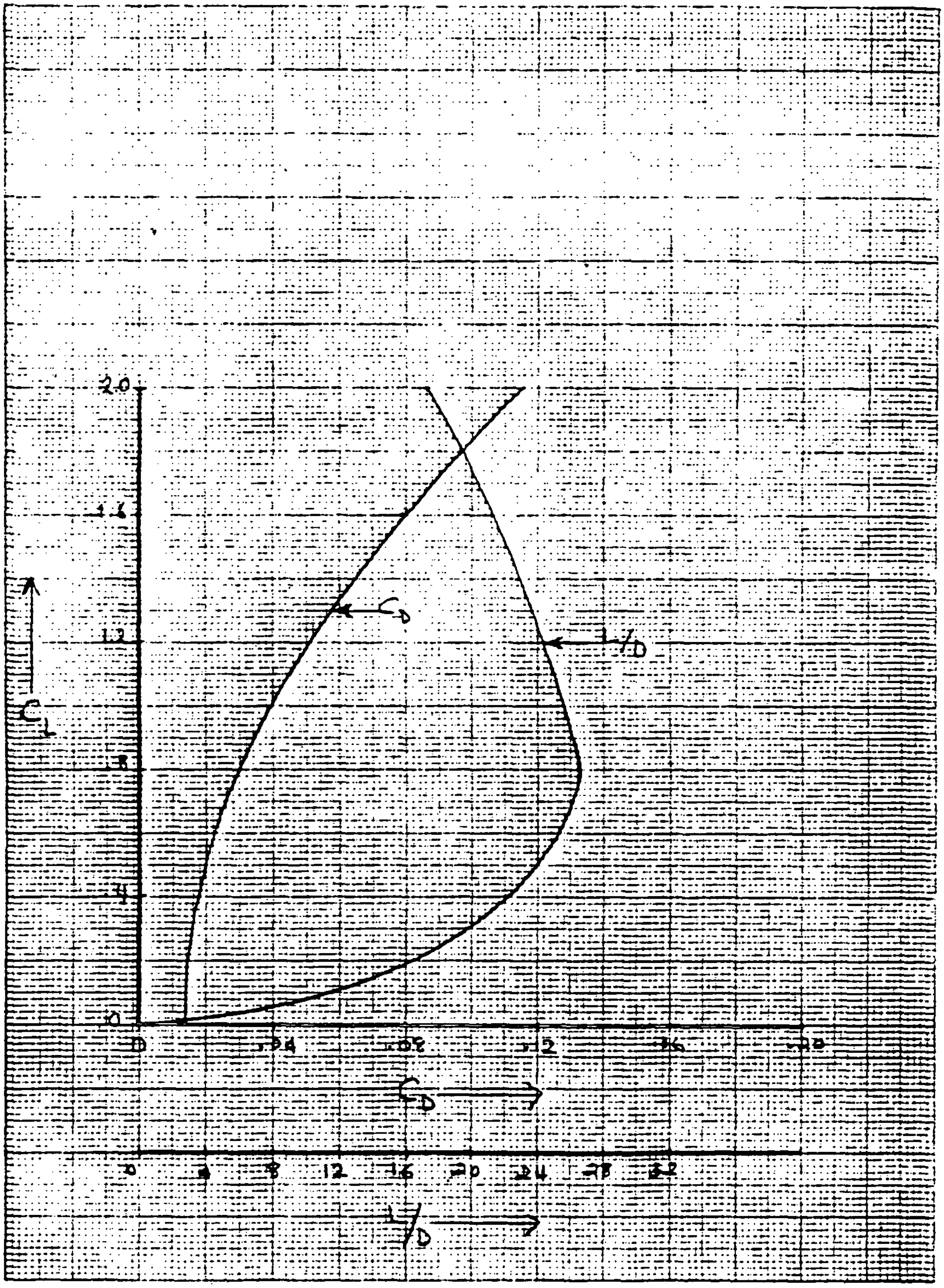

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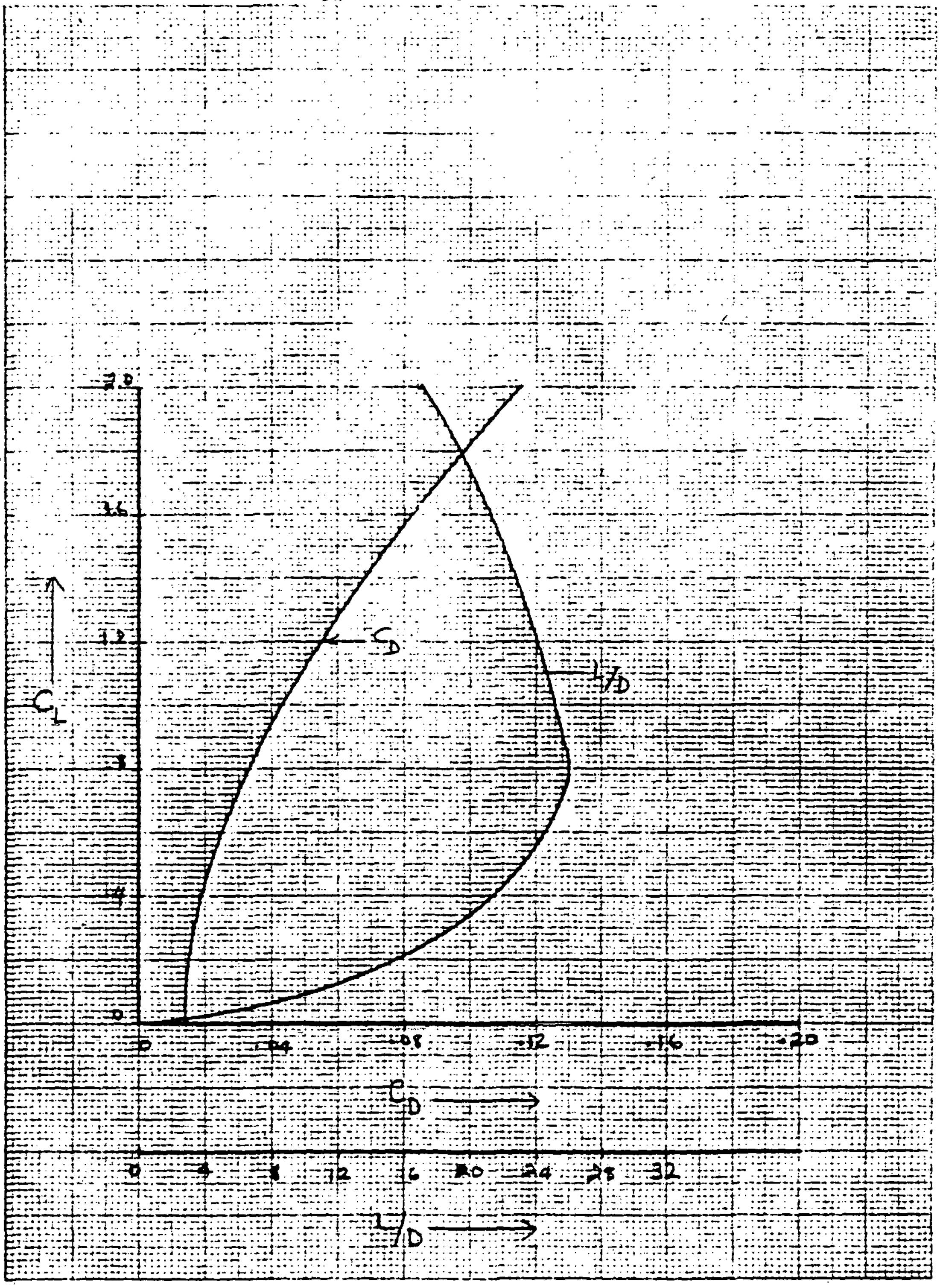

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Figure 6.5 100 Passenger
Cruise Drag Polar

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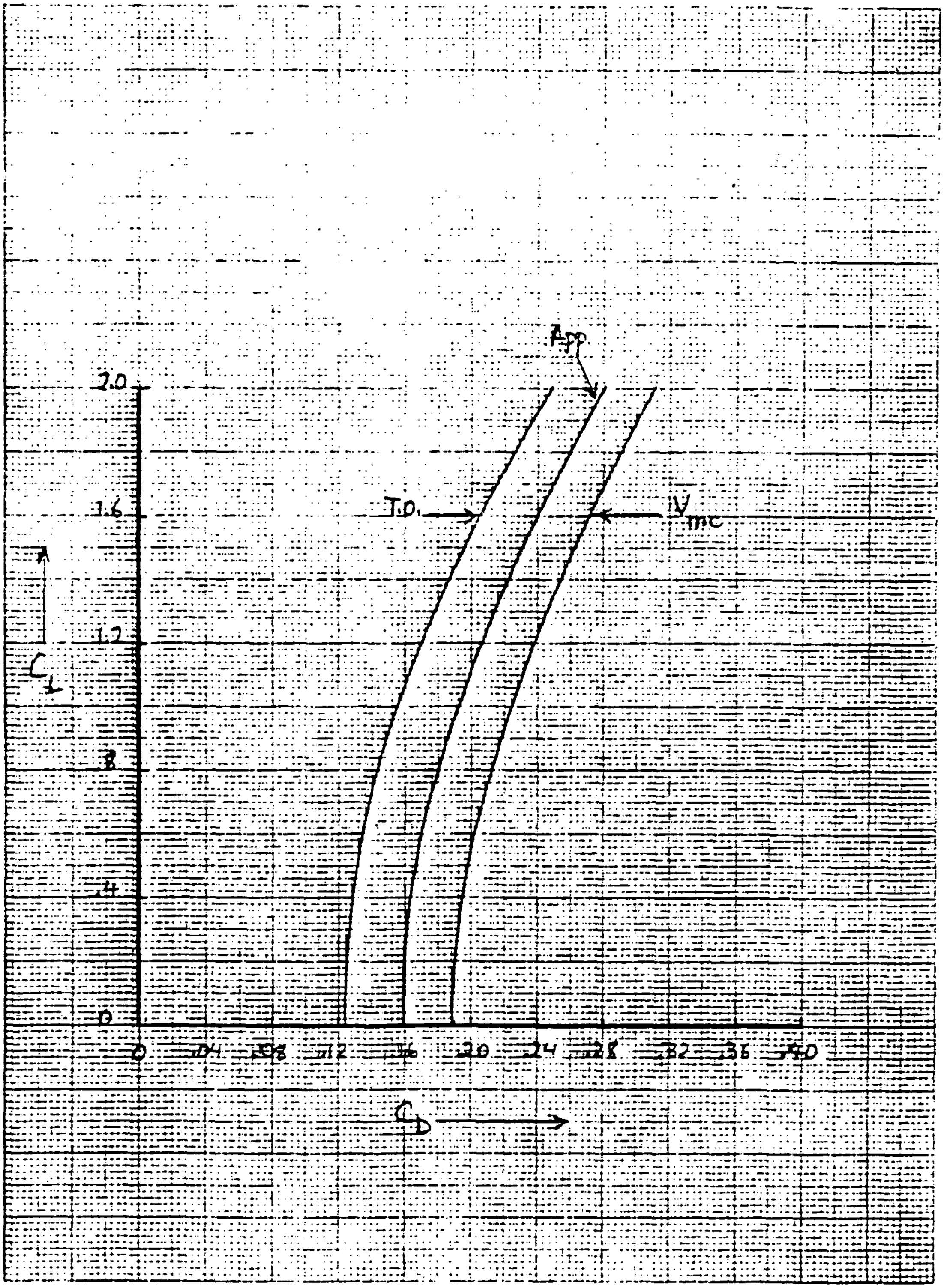

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Figure 6.6 25 Passenger Approach Drag Polar

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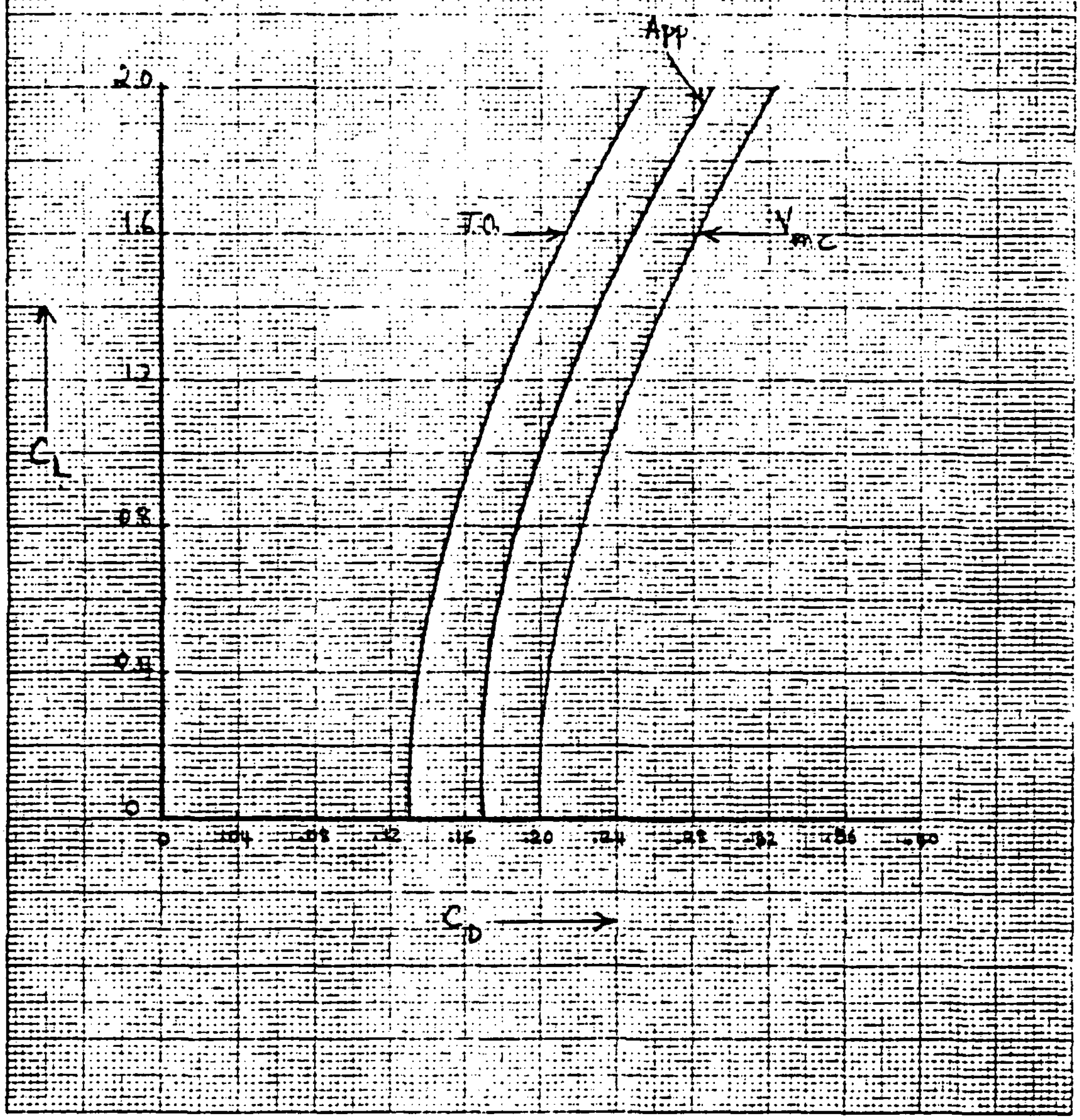

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Figure 6.7 36 Passenger Approach Drag Polar

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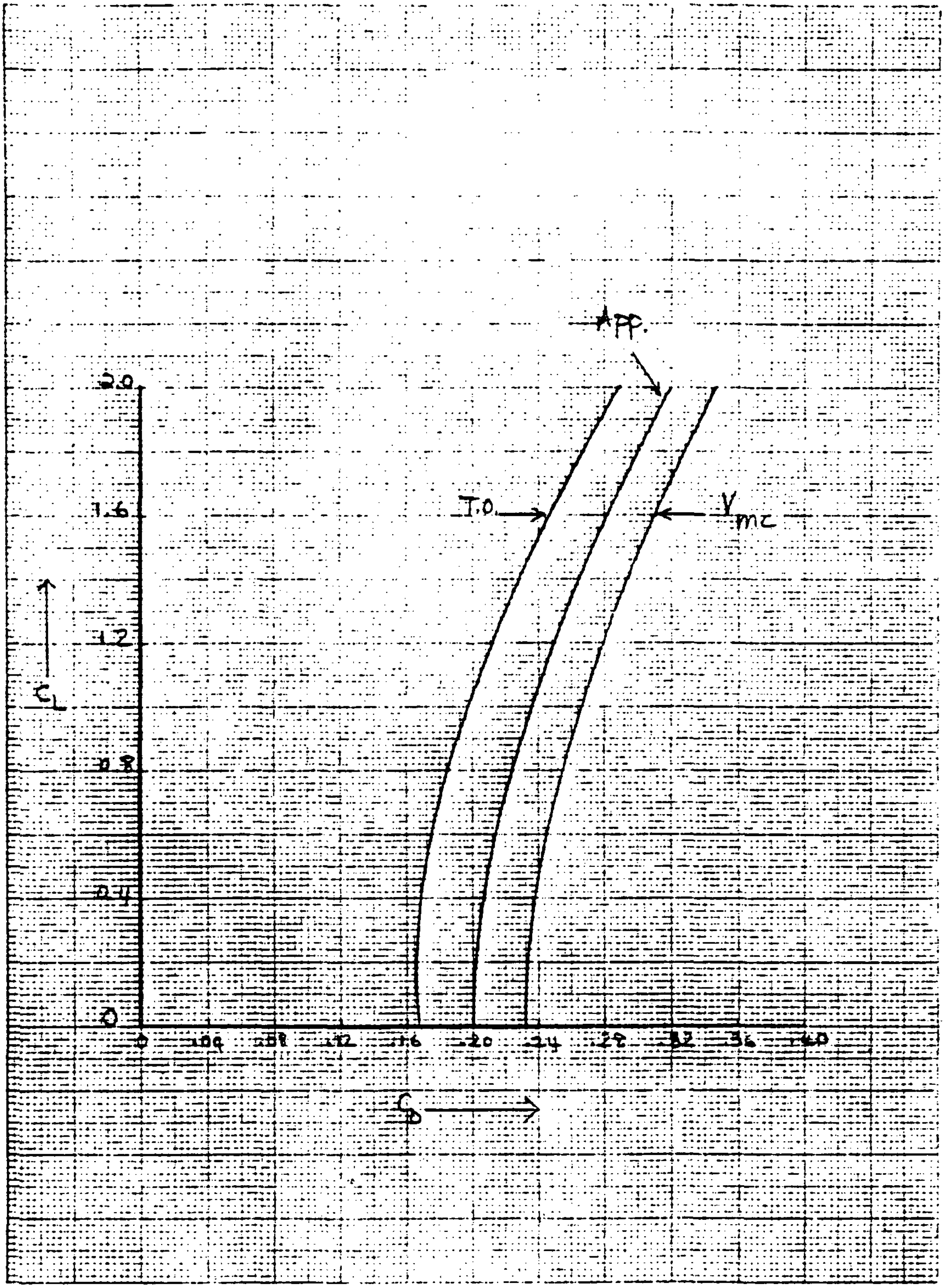

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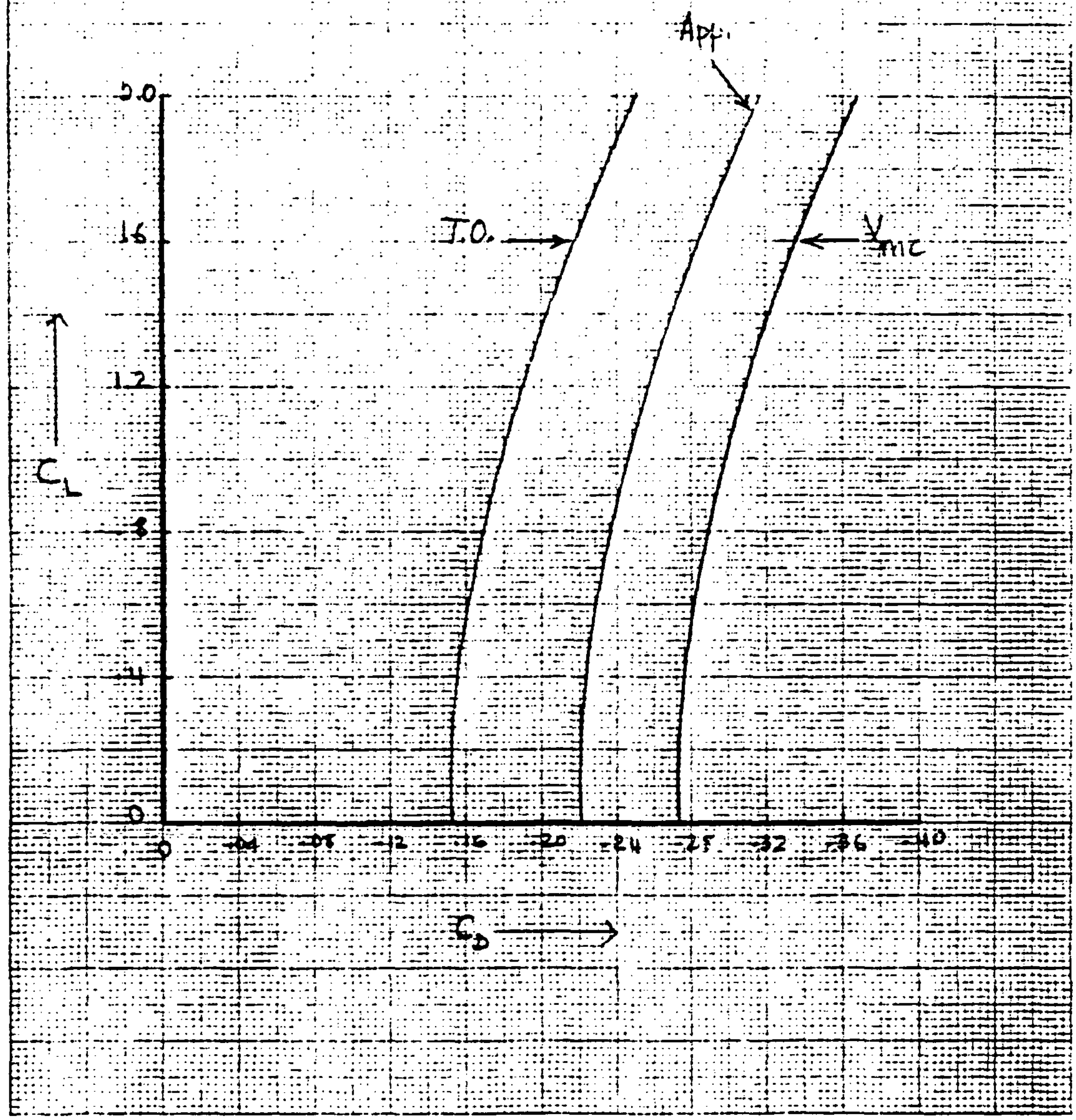

CALC			REVISED	DATE	Figure 6.9 75 Passenger Approach Drag Polar	
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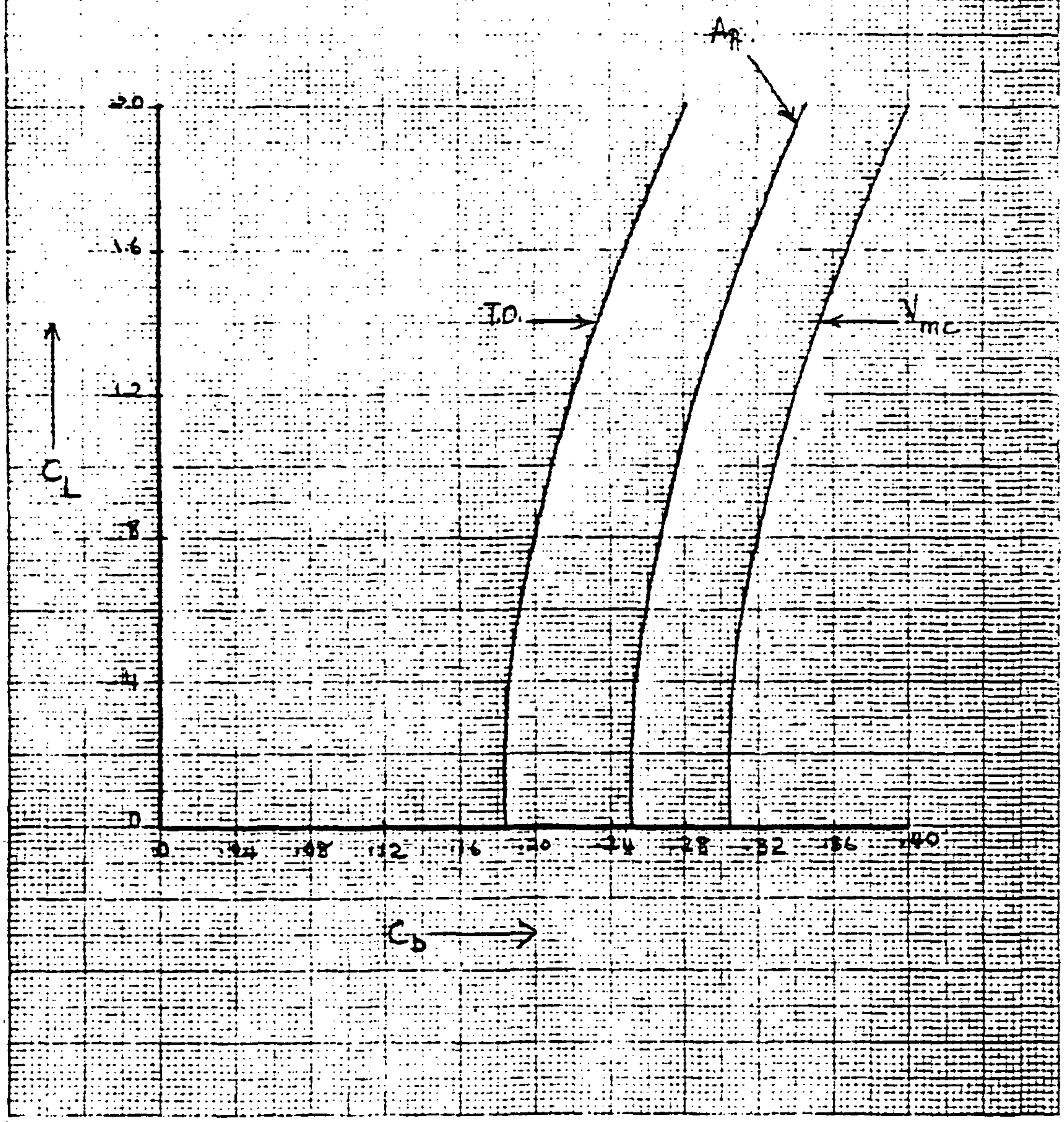

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7.0 VERIFICATION OF MISSION PERFORMANCE

The purpose of this section is to verify the mission performance obojectives for the family of commuter airplanes. These objectives must be verified with the current configurations, which include all design changes made for the purpose of commonality.

The mission profile for the airplane family is given in Figure 7.1. Note that the following common performance characteristics have now been designed into all of the configurations.

Common take-off and landing field lengths (under 3500ft)

Common approach and take-off speeds ($V_A = V_{TO}$)

Common climb gradients (meet FAR 25)

Common cruise and service ceilings

The above objectives are discussed in the following subsections, including descriptions of how the numerical values were obtained.

7.1 Field Length Verification

7.1.1 Take-off Distance

The take-off distances were calculated using one of the methods in Chapter 10 of Reference 14. The calculations were done on a spreadsheet program, using the equations listed in Appendix H. A printout of the spreadsheed calculations is also given in Appendix H.

The take-off distance calculations were done in such a way that the take-off stall speed was input. Iterations were then made until every airplane achieved a take-off field length of just less than 3500 feet. Two assumptions were made:

1) A runway inclination angle of zero degrees.

2) A ground friction coefficient of 0.025.

The final values for take-off field length (LFL) are given in Table 7.1.

C-2

1) Engine Start and Warm-up
2) Taxi
3) Take-off
4) First Segment Climb
   V = 250 kts
   h = 10,000 ft
5) Second Segment Climb
6) Cruise, M = 0.7, 30,000 ft
7) Descent
8) Landing, Taxi, and Shutdown

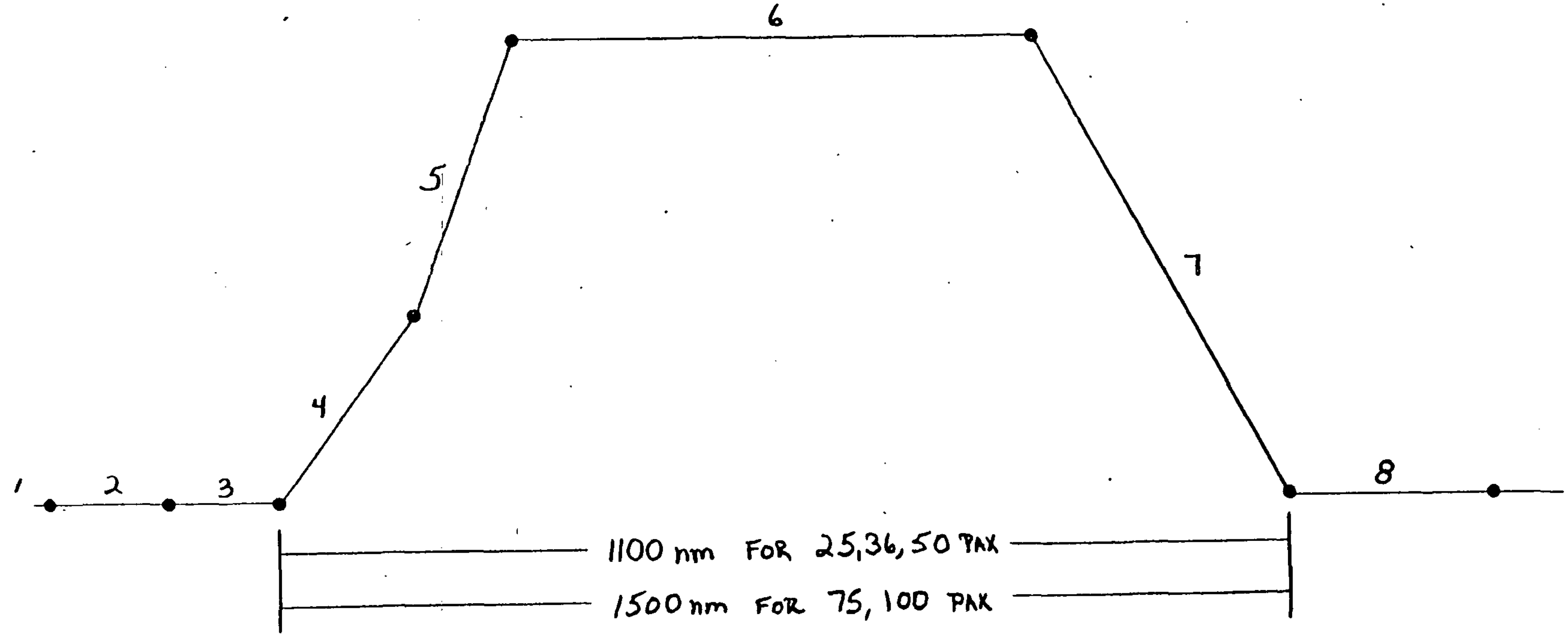

Figure 7.1 Mission Profile for the Commuter Family

7.1.2 Landing Distance

The landing distances were also calculated using a method in Chapter 10 of Reference 14. The equations used are given in Appendix H. The spreadsheet calculations are also shown.

A common value for approach velocity was input, then iterations were made until the landing distance for every airplane was just under 3500 feet. Two assumptions were made:

1) A braking coefficient of 0.51.

2) An approach descent angle of 3° (common glideslope angle)

The final values for landing field length (LFL) are given in Table 7.1.

Table 7.1 - Field Lengths

Model	Required	TOFL	LFL
25	3500 ft	3325 ft	3365 ft
36	3500 ft	3414 ft	3467 ft
50	3500 ft	3403 ft	3468 ft
75	3500 ft	3484 ft	3337 ft
100	3500 ft	3465 ft	3370 ft

7.2 Verification of FAR 25 Climb Gradients

The climb gradients for each segment as specified in FAR 25 are calculated using the following equations (from Ref. 1):

$R.C. = (T_{AV}/W - C_D/C_L) \times (2W/\rho C_L S)^{.5}$

Climb Gradient = $R.C. / U_1$

The required climb gradients and the flight conditions for which they apply, as specified by FAR 25, are listed in Table 7.2. The actual climb gradients are calculated on a spreadsheet program. A printout of the spreadsheet calculations is given in Appendix H. The results of the calculations are given in Table 7.3.

7.3 Verification of Range Requirements

It is desired that the 25, 36 and 50 passenger models travel 1100 n.m. with full payload. The 75 and 100 passenger models

Table 7.2

Climb Requirements

#	FAR Req.	Flap Set	Gear Set	V xVs	Thrust Set	Wt.	Climb Grad. %
1	25.111 OEI initial	TO	up	1.2	TO	TO	1.2
2	25.121 OEI transition	TO	down	1.15	TO	TO	0
3	25.121 OEI 2nd segment	TO	up	1.2	TO	TO	2.4
4	25.121 OEI en route	clean	up	1.25	MC	TO	1.2
5	25.119 AEO landing	landing	down	1.3	TO	L	3.2
6	25.121 OEI landing	approach	down	1.1<V <1.5	TO	L	2.1

Table 7.3

Actual Climb Gradients for the Commuter Family

Climb Reqmt. #	25	36	50	75	100
1	10.79	11.10	10.04	13.77	12.93
2	5.86	6.99	6.52	4.76	4.96
3	10.79	11.10	10.04	13.77	12.93
4	9.92	11.20	13.24	11.02	12.83
5	26.70	26.65	23.71	23.30	22.01
6	5.20	5.24	3.24	3.78	2.76

1500 n.m. with full payload. Figure 7.2 presents payload-range diagrams for the commuter family. From this figure it can be seen that the range requirements were met. A cruise sfc of .36 (lb/hp/hr), and a propeller efficiency of .86 were used in the range calculations.

7.4 Rate-of-Climb Requirements

The commuter family is to have a 3000 fpm climb rate at sea level. Also, 100 fpm climb rate at 30,000 ft (cruise). Table 7.4 contains the results of the rate of climb calculations. Notice the 100 passenger model does not meet the requirements of 3000 fpm at sea level.

Table 7.4 Rate-of-Climb Results

Model	Sea Level	10,000 ft	30,000 ft
25	3138	4693	984
36	3053	4128	573
50	3064	4433	1224
75	3753	5763	2150
100	2534	4684	1568

Rate of Climb in fpm

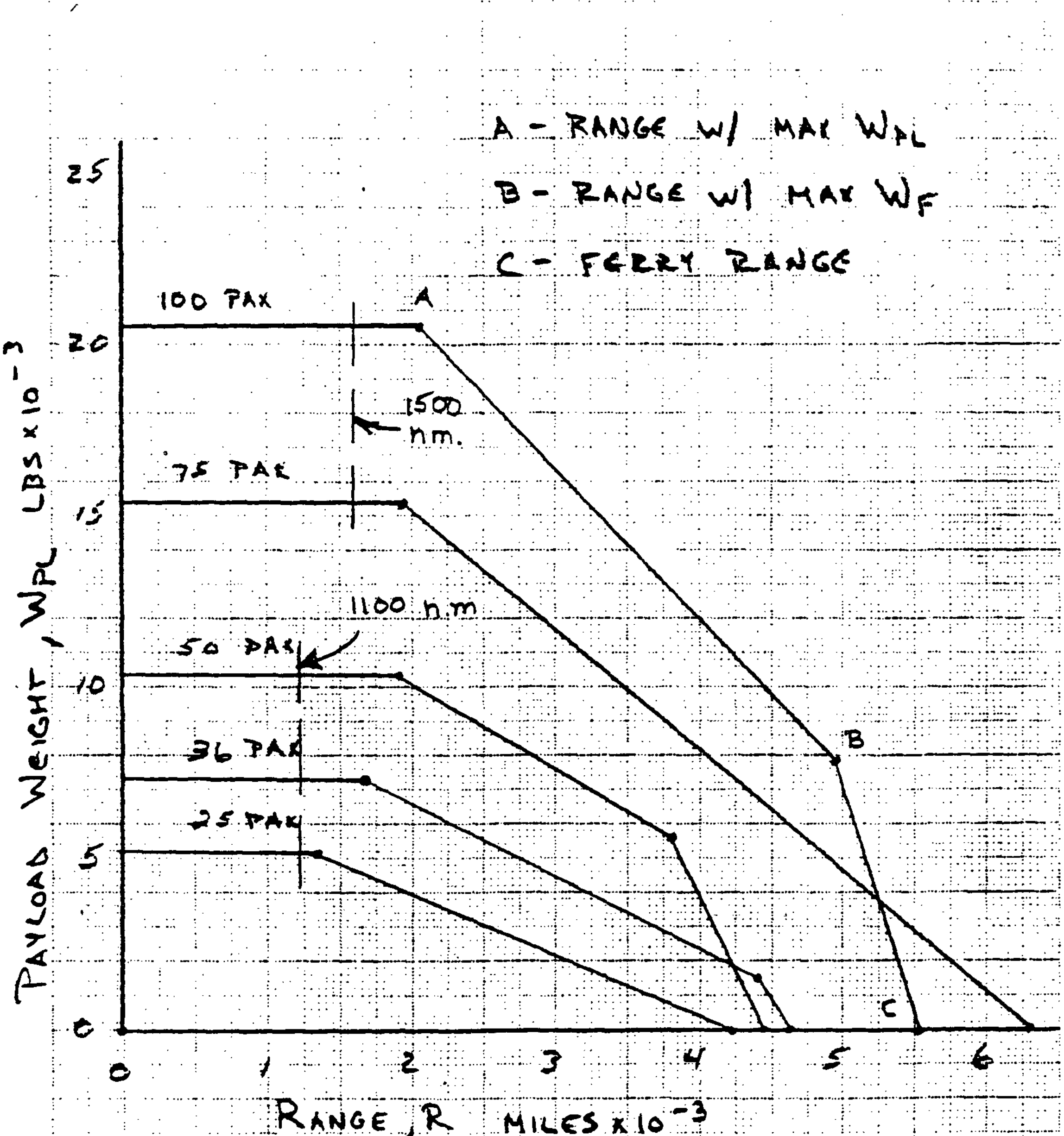

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Figure 7.2 Payload Range Diagrams

8.0 Commonality Analysis of the Commuter Family

Now that the Class II designs for the commuter family have been presented, the extent of commonality that was implemented needs to be discussed. Table 8.1 shows the status of the commonality objectives.

The following items are common to all members of the commuter family:

1. Common fuselage cross section.
2. Common flight deck layout.
3. Common cockpit instrumentation.
4. Common landing gear system design.
5. Common tailcone-empennage-engine integration.
6. Common wing design.
7. Common powerplants.
8. Common airfoil.
9. Common flight control system.
10. Common fuel system.
11. Common pressurization system.
12. Common de-icing system.
13. Common dynamic handling qualities.
    (only with SSSA system)

The twin-body concept is extremely conducive to commonality implementation with the smaller commuters. This allows for more commonality throughout the passenger range.

The wing areas of the 75 and 100 passenger conventional configurations were too large to implement a common torque box carry-through structure. See section 2.2. Also, the lateral gear spacing was too large to accommodate similar gear struts with the smaller members of the family. The 100 passenger conventional model would require 8 tires per bogey on the main gear, while the twin-body 100 passenger only needed 4 wheels per bogey. Empennage sizes were too large to retain common surfaces on all family members. The conventional 75 and 100 passenger models required 2500 more SHP and the take-off weights were much

Table 8.1--Status of Commonality in the Commuter Family.

Airplane Type	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax
Structural Commonality:					
Tailcone Arrangement	Yes	Yes	Yes	Yes	Yes
Wing Design	Yes	Yes	Yes	Yes	Yes
Fuselage Cross Section	Yes	Yes	Yes	Yes	Yes
Landing Gear	Yes	Yes	Yes	Yes	Yes
Systems Commonality:					
Cockpit Instrum.	Yes	Yes	Yes	Yes	Yes
Dynamic Handling Qualities	Yes	Yes	Yes	Yes	Yes
Stick Forces and Gradients	No	No	No	No	No
Fuel System	Yes	Yes	Yes	Yes	Yes
De-Icing	Yes	Yes	Yes	Yes	Yes
Pressurization	Yes	Yes	Yes	Yes	Yes
Flight Controls	Yes	Yes	Yes	Yes	Yes
Engine Commonality:					
2 Engines	Yes	Yes	Yes	Yes	Yes
5500 shp	Yes	Yes	Yes	No	No
11,000 shp	No	No	No	Yes	Yes

greater. From reasons discussed in Reference 5, two different SHP turbo-prop engines will be used to span the passenger models. Table 8.1 shows which engines are integrated into the airplanes of the family. The design of common dynamic handling of the family and the implementation of a SSSA system are contained in Reference 6.

8.1 Weight Penalties and Cost Savings Due to Commonality

This section summarizes the take-off weight penalties and cost savings that arise due to the design of commonality. Table 8.2 summarizes the weight penalties associated with commonality. Table 8.3 details the cost of the family. Figure 8.1 compares baseline designs with the common family designs. A savings of $1.3 million per airplane is realized due to commonality. However, there is a 12% weight penalty for the 25 passenger model.

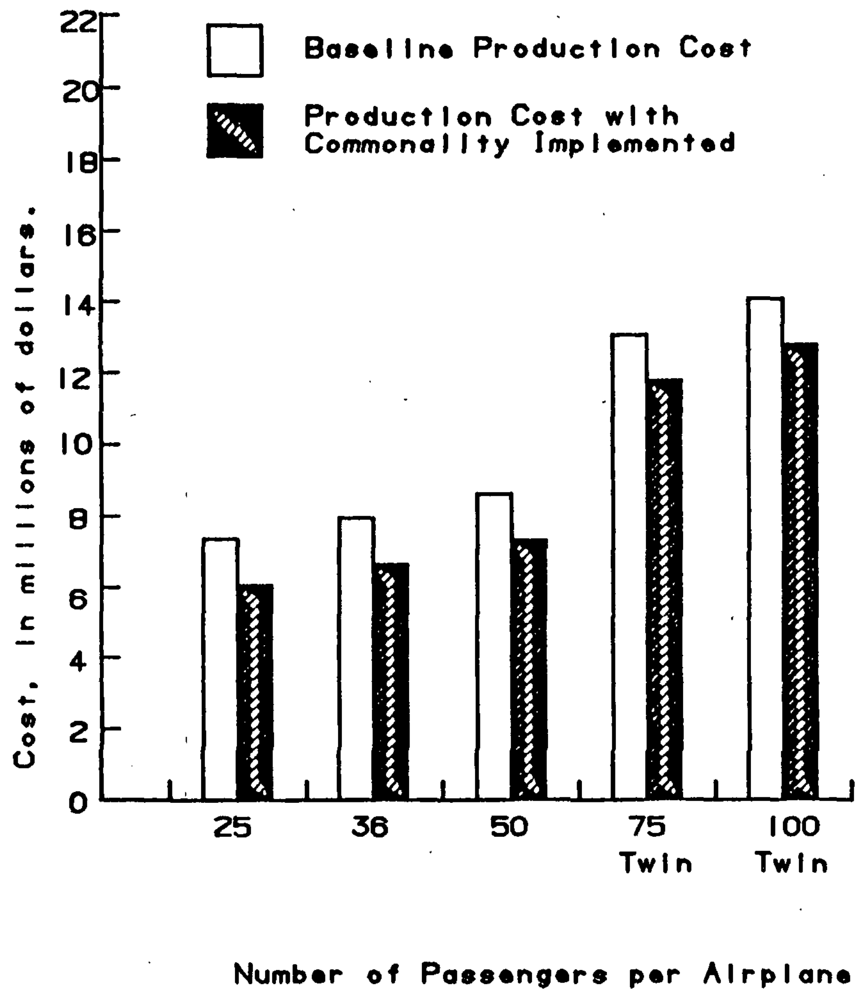

Figure 8.1--Cost Comparison for NASA Family of Commuters.

Table 8.2a

Weight Penalty Imposed By Commonality Over Class II Baseline

Model:	25	36	50	75	100
ΔW_W	1312	924	0	1281	0
ΔW_{FUS}	176	92	0	184	0
ΔW_{EMP}	134	108	0	66	0
$\Delta W_{L.G.}$	803	405	0	1065	355
ΔW_{PWR}	624	476	0	1051	0
ΔW_{TO}	3049	2005	0	3647	355
% Diff. over Class II baseline	12.0	5.9	0	5.4	0.4

Table 8.2b

Summary of Class II Weights Implementing Commonality

W_{TO}	28506	35954	43141	71419	85044
W_E	19099	22182	25153	43671	49426
W_{PL}	5125	7380	10250	15375	20500
W_{CR}	410	615	615	820	820
W_{tfo}	105	157	210	313	420
W_F	3767	5620	6913	11240	13878
ΔW_{TO}	3049	2005	0	3647	355
% Change Above Baseline W_{TO}	12.0	5.9	0	5.4	0.4

Table 8.3a --Average Savings Per Category Due to Common Production Parts and Processes.

Component	Tooling	Man Lab	Mat & Eq	Q/C	Total
Nose Gear	11037	61542	3961	8000	84540
Main Gear	36026	198400	15603	25793	275822
Ver. Tail	14376	87277	12114	11346	125113
Hor. Tail	8558	46579	2627	6055	63819
Fus. Secs	74420	359756	-6649	46770	474297
Wing	40742	203108	4587	26405	274842
Totals	185159	956662	32243	124369	1298433

Table 8.3b --Comparison of Acquisition Costs.

Airplane Size	Initial Prod. (incl. DT&E)	Production Baselines	Commonality Implemented
25 Pax	8667362	7363869	6065436
36 Pax	9490391	7948048	6649615
50 Pax	10428089	8611920	7313487
75 Pax	15682836	13069259	11770826
100 Pax	17121109	14079259	12780826

9.0 Comparison of Commuter Family to Existing Airplanes

The purpose of this chapter is to compare data from the commuter family with existing regional turbo-propeller driven airplanes. The larger members of the commuter family will be compared with smaller jet transports. Take-off weights, center of gravity excursion range, wetted areas, wing loadings, cabin and baggage volumes, and cost of the airplanes will be compared. These comparisons will attempt to prove the validity of the class II designs.

9.1 Comparison of Take-off Weights

Figure 9.1 shows the commuter family take-off weights compared with existing airplanes. The commuter family was sized assuming an 8% structural weight savings due to the use of advanced structural materials. Aramid aluminum will be utilized to achieve this structural weight savings. Appendix E contains data for this composite material.

9.2 Center of Gravity Excursion

Table 9.1 contains the excursion range of the center of gravity for the commuter family. These data are compared with common excursion ranges for regional turbo-propeller and jet transport airplanes taken from Reference 15.

From Table 9.1 it can be seen that all the class II designs have C.G. excursion ranges comparable with contemporary airplanes.

9.3 Comparison of Airplane Wetted Areas

Wetted areas of the commuter family are compared to regional turbo-propeller and jet transports wetted areas. Figure 9.2 compares the wetted areas of the commuter airplanes with existing airplanes. It can be seen that these airplanes compare favorably with existing regional turbo-propeller and jet transport airplanes.

9.4 Comparison of Airplane Wing Loadings

Wing loadings of the commuter family are compared to existing commuters and jet transports. Table 9.2 lists wing loadings of some existing airplanes. Table 9.3 lists wing loadings for the commuter family. The comparison shows that the commuter family wing loadings are higher than typical commuters but less than jet transports.

9.5 Comparison of Acquisition Costs

Figure 9.3 compares the commuter family to other commuters on an acquisition cost basis. Existing prices were taken from Interavia, May 1986.

Table 9.1 CENTER OF GRAVITY EXCURSION RANGE COMPARISON

AIRPLANE MODEL	RANGE OF C.G. TRAVEL		COMMON EXCURSION RANGES	
25 passenger	12"	$.13\bar{c}$	12"-20"	$.14 - .27\ \bar{c}$
36 passenger	12"	$.13\bar{c}$	12"-20"	$.14 - .27\ \bar{c}$
50 passenger	6"	$.09\bar{c}$	12"-20"	$.14 - .27\ \bar{c}$
75 passenger	18"	$.17\bar{c}$	12"-20"	$.14 - .27\ \bar{c}$
100 passenger	15"	$.14\bar{c}$	12"-20"	$.14 - .27\ \bar{c}$

Table 9.2 WING LOADINGS OF EXISTING AIRPLANES

Airplane	Pax	$(W/S)_{TO}$ psf
Beech 1900	19	50
DHC-6-300	20	30
BAe 31	18	54
METRO III	19	47
CASA C-212-200	28	38
DHC-8	37	52
EMB-120	30	52
Shorts 330	30	51
Fokker F27-200	52	60
DHC-7	50	67
Fokker F-28	85	86
BAe 146-200	100	108

Table 9.3 WING LOADINGS FOR THE COMMUTER FAMILY

Airplane Model	$(W/S)_{TO}$ psf
25 Passenger	50
36 Passenger	60
50 Passenger	70
75 Passenger	60
100 Passenger	72

9.6 Comparison of Cabin Volume With Existing Airplanes

Passenger and baggage volume are compared with existing airplanes in Table 9.4.

Table 9.4 COMPARISON OF CABIN AND BAGGAGE VOLUMES WITH EXISTING AIRPLANES

Airplane Type	Number of Passengers	Overhead Baggage Volume (cuft)	Overhead Volume per Seat (cuft)
NASA			
50, 100	50	56	1.1
36, 75	36	41	1.1
25	25	29	1.2
British Aerospace			
BAe Super 748	46	41	0.85
BAe ATP	48	100	1.6
BAe 146-100	64	56	0.68
de Havilland			
DASH 7	50	59	1.2
DASH 8	37	32	0.86
Fokker			
F-27	52	40	0.77
50	50	79	1.6
F-28	65	107	1.6
Shorts			
330	30	40	1.3
360	36	52	1.4
ATR Consortium			
ATR 42-200	46	53	1.2
Embraer			
EMB-120	30	32	1.1

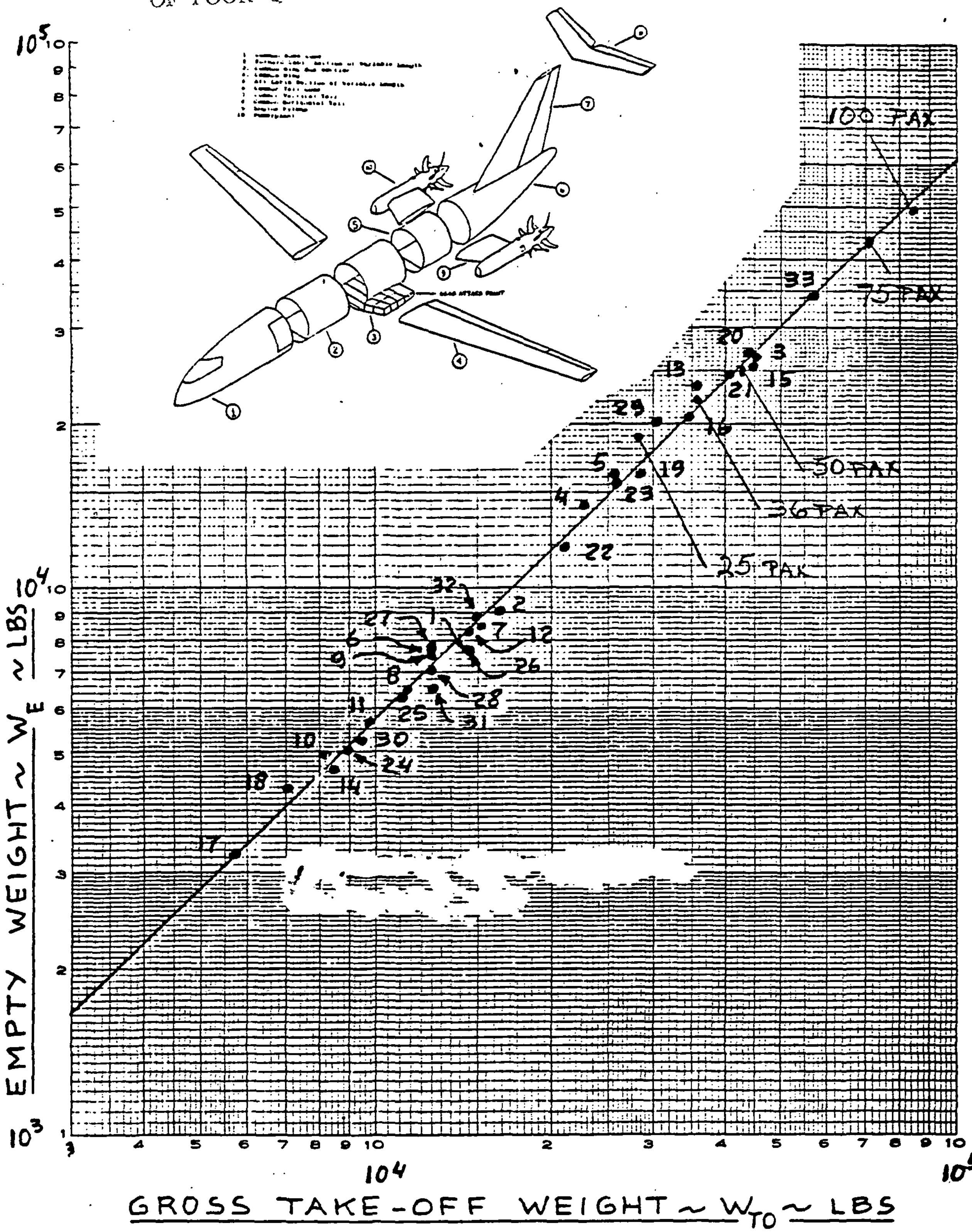

Figure 9.1 Weight Trends for Regional Turbo-Propeller Driven Airplanes

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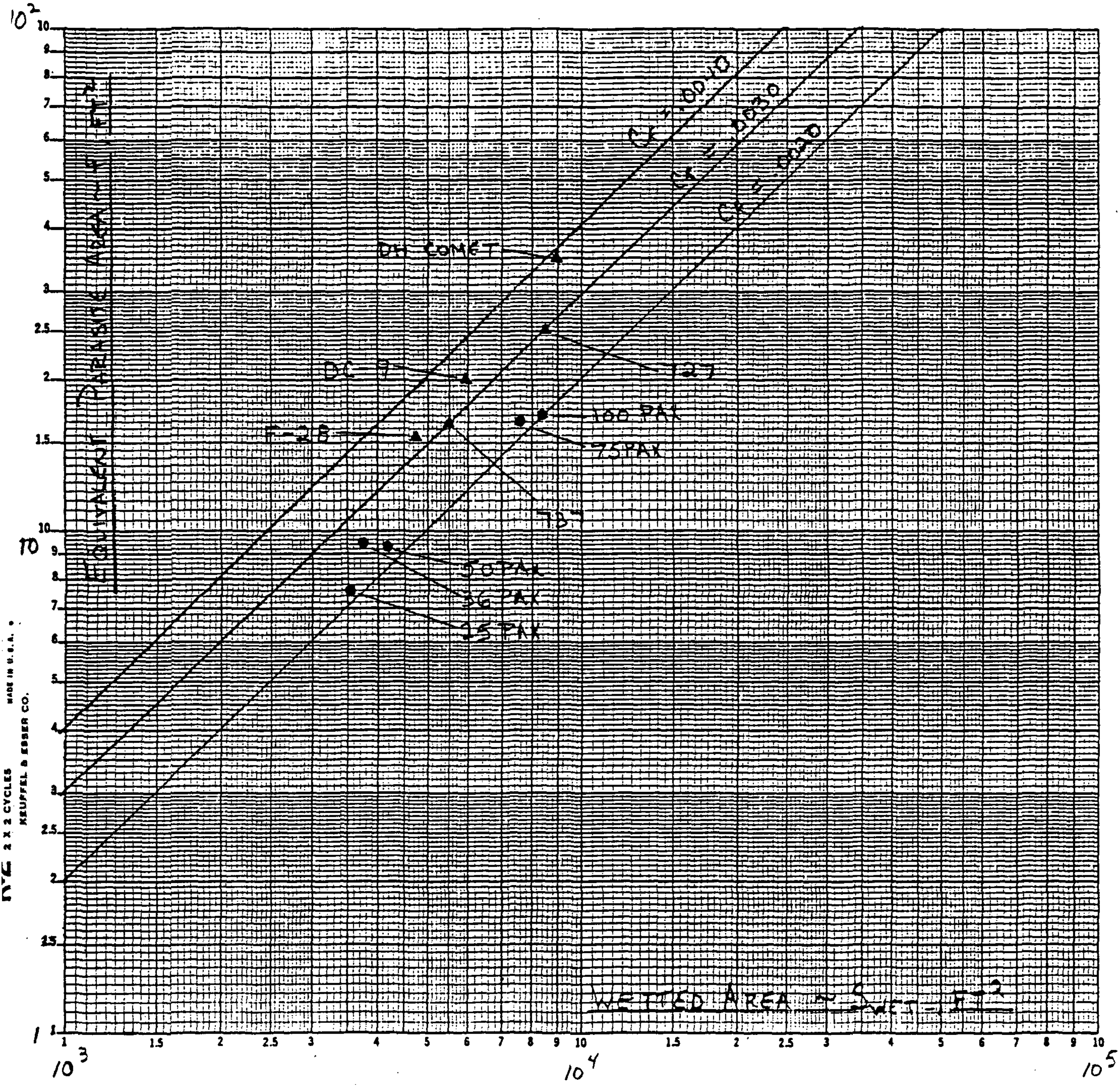

Figure 9.2 Wetted Area Comparison For the Commuter Family

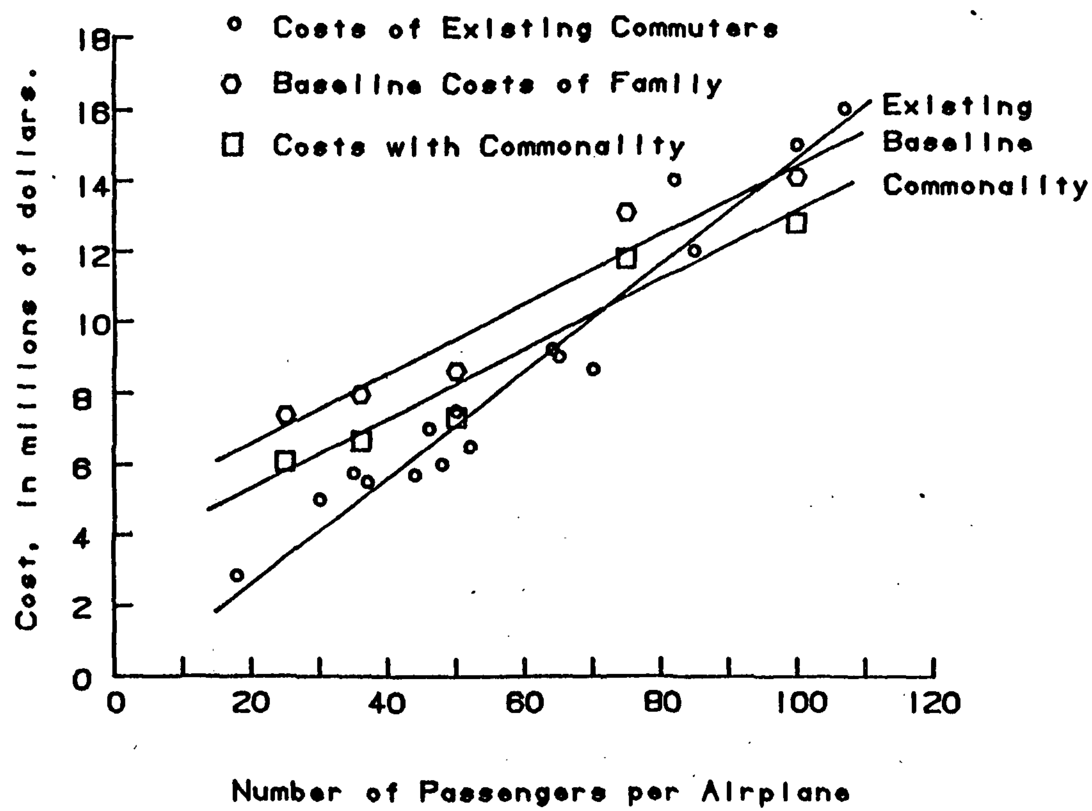

Figure 9.3 --Cost Comparison for Existing Commuters and the Proposed Family of Commuters.

10.0 Conclusions and Recommendations

10.1 Conclusions

1) The commonality approach toward designing a family of airplanes must begin at the beginning of the preliminary design process.

2) A fmaily of commuter airplanes have been designed. These airplanes range from 25 to 100 passengers.

3) TakeOoff weights range from 28,506 lbs to 85,044 lbs.

4) The design of a commuter family of airplanes with commonality is feasible if the twinbody concept is used.

5) The following commonality objectives have been integrated into the commuter family:

- Common fuselage cross section
- Common landing gear system
- Common wing design
- Common empennage/tailcone/engine arrangement
- Common powerplants (2)
- Common cockpit instrumentation
- Common NLF airfoil
- Common flight control system
- Common fuel system
- Common pressurization system
- Common de-icing system
- Common dynamic handling qualities

6) Large take-off weight penalties have occured (12% on the 25 passenger airplane).

7) Cost savings of about $1.3 million per airplane have occured due to commonality.

8) Performance objectives met, except the 100 passenger model does not have a 3000 fpm rate of climb at sea level.

9) Stick forces and gradients will require rebalancing of the configurations to meet FAR requirements.

10.2 Recommendations

1) The airplanes should be taken through the following design iterations:

a) Redesign gearbox to reduce engine nacelle diameter.

b) Reiterate the class II weight estimation.

c) Set static margin stick fixed such that the airplanes will be pitch-trimmable and not have an unstable stick fixed margin.

d) Stick force commonality throughout the family may then be possible.

2) Better methods for hinge-moment derivatives should be found. As a small change in hinge moments can cause large differences in the cockpit stick forces and gradients.

3) A family approach to the design of commuters and transports should be considered as an economically attractive opportunity for U.S. airplane manufacturers.

11.0 REFERENCES

1) University of Kansas AE 790 Design Team; Class I Designs of a Family of Commuter Airplanes; University of Kansas, 1986.

2) Morgan, L.K., University of Kansas AE 790 Design Team; A Cost Analysis for the Implementation of Commonality in the Family of Commuter Airplanes; University of Kansas, April 1987.

3) University of Kansas AE 790 Design Team; A Class II Weight Assessment for the implementation of Commonality and Preliminary Structural Dsigns for the Family of Commuter Airplanes; University of Kansas, 1987.

4) Russell, M., and Haddad, R., University of Kansas AE 790 Design Team; Presentation of Structural Component Designs for the Family of Commuter Airplanes; University of Kansas, 1987.

5) Swift, G., University of Kansas AE 790 Design Team; Advanced Propfan Analysis for the Family of Commuter Airplanes; University of Kansas, May 1987.

6) Hensley, D., University of Kansas AE 790 Design Team; Flight Control Design and Handling Quality Comonality by Seperate Surface Stability Augmentation for the Family of Commuter Airplanes; University of Kansas, May 1987.

7) Kohlman, D.L., Schweikhard, W.G., Albright, A., Evanich, P., "Icing Tunnel Tests of a Glycol-Exuding Porous Leading Edge Ice Protection System on a General Aviation Airfoil"; KU-FRL-464-1 University of Kansas Center for Research, Inc., Lawrence, KS., May 1981.

8) Roskam, J., Airplane Design: Part I, Preliminary Sizing of Airplanes, Roskam Aviation and Engineering Corporation, Ottawa, KS, 1985.

9) Abbott, I.H. and Von Doenhoff, A.E., Theory of Wing Sections, Dover Publications, Inc., N.Y., 1959.

10) Roskam, J., Airplane Flight Dynamics and Automatic Flight Controls, Parts I and II, Roskam Aviation and Engineering Corporation, Ottawa, KS, 1979.

11) Grantham, et al, "Ground Based and In-flight Simulator Studies of Flight Characteristics of a Twin-fuselage Transport Airplane During Approach and Landing"; NASA TM-2451, Sept. 1985.

12) Hoak, D.E.; Ellison, D.E. et al; USAF Stability and Control Datcom; Flight Control Division; Air Force Flight Dynamics Laboratory, Wright Patterson Air Force Base, Ohio.

13) Roskam, J., Airplane Design: Part VI, Preliminary Calculation of Aerodynamic, Thrust and Power Characteristics, Roskam Aviation and Engineering Corporation, Ottawa, KS, 1987.

14) Lan, C.E.; Roskam, J.; Airplane Aerodynamics and Performance, Roskam Aviation and Engineering Corporation, Ottawa, KS, 1980.

15) Roskam, J., Airplane Design: Part II, Preliminary Configuration Design and Integration of the Propulsion System, Roskam Aviation and Engineering Corporation, Ottawa, KS, 1985.

16) Roskam, J., Methods for Estimating Stability and Control Derivatives of Conventional Subsonic Airplanes, Roskam Aviation and Engineering Corporation, Ottawa, KS, 1971.

APPENDIX A

COCKPIT AND FUSELAGE ARRANGEMENTS

TABLE OF CONTENTS

A.1 FUSELAGE CROSS SECTION

From Figure A.1 it is seen that many commuter airplanes in the 20 to 65 passenger range have 4-abreast seating. This range of passenger capacity spans over half of the required passenger capacity of the family. For this reason 4-abreast seating was selected.

Figure 2.1 shows the selected fuselage cross section to be used in all of the airplanes in the NASA commuter family. The overhead storage volume calculated in this section is compared with that of other commuter airplanes in tables A.1 and 4.4.

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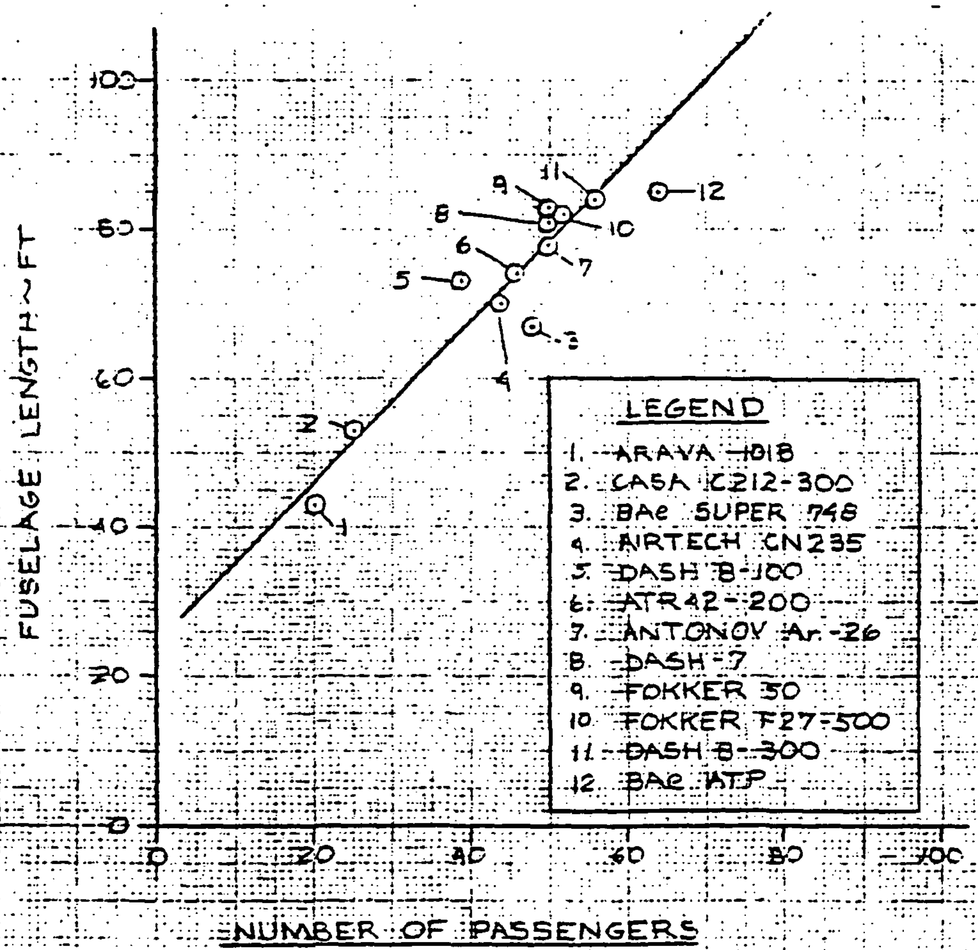

CALC			REVISED	DATE	FIGURE A.1: FUSELAGE TRENDS	
CHECK						
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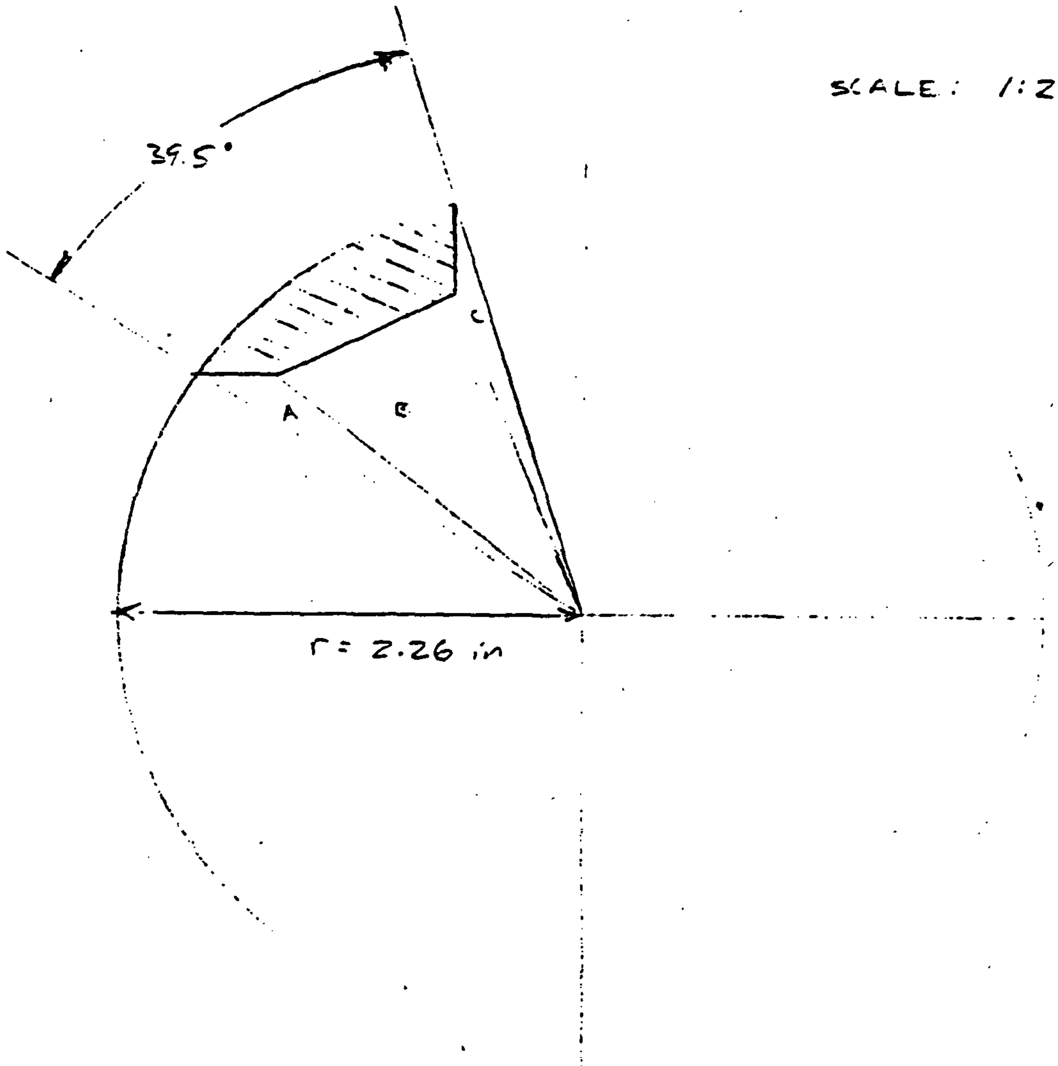
A.1.1 DETERMINATION OF OVERHEAD BAGGAGE VOLUME

JERRY ROBINSON | OVERHEAD BAGGAGE VOLUME | NASA 25-36-50

OVERHEAD VOLUME



SCALE: 1:20 INCHES

AREA OF SECTOR $= \frac{1}{2} r^2 \theta$ (θ in RADIANS)

$$= \frac{1}{2} (2.26)^2 (39.5°) \left(\frac{\pi}{180}\right)$$

$$= 1.76 \text{ in}^2$$

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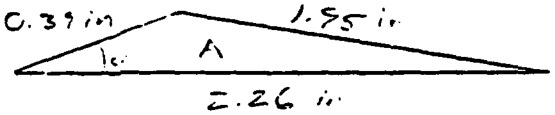
AREA OF TRIANGLE A:



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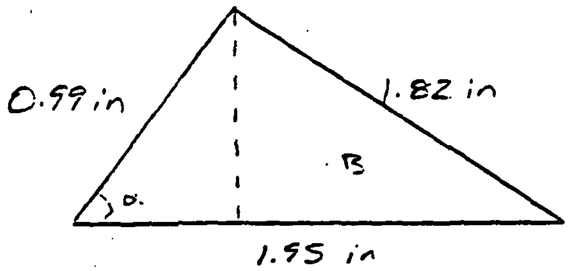
$\alpha = 34.2°$ $\therefore$ $h = 0.22$ in

$A = \frac{1}{2} bh = \frac{1}{2}(2.26)(0.22) = 0.25 \text{ in}^2$

AREA $A = 0.25 \text{ in}^2$

AREA OF TRIANGLE B:



(NOT TO SCALE)

$\alpha = 67.6°$ $\therefore$ $h = 0.92$ in

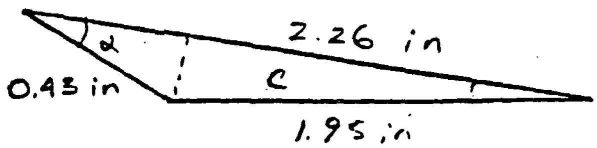
$A = \frac{1}{2} bh = \frac{1}{2}(1.95)(0.92) = 0.90 \text{ in}^2$

AREA B $= 0.90 \text{ in}^2$

AREA TRIANGLE C

$\alpha = 40°$ $\therefore$ $h = 0.28$ in

$A = \frac{1}{2} bh = \frac{1}{2}(2.26)(0.28) = 0.32 \text{ in}^2$



(NOT TO SCALE)

AREA OF OVERHEAD STORAGE

$$A = (1.76\ in^2) - (0.25\ in^2) - (0.90\ in^2) - (0.32\ in^2)$$

$$A = 0.29\ in^2$$

$$A = 116\ in^2 = 0.81\ ft^2$$

50 PASSENGER OVERHEAD VOLUME

$$V = \frac{(0.81\ ft^2)(8.5\ in)(50\ in/in) + (0.81\ ft^2)(8\ in)(50\ in/in)}{(12\ in/ft)}$$

$$\boxed{VOLUME = 56\ FT^3}$$

36 PASSENGER OVERHEAD VOLUME

$$V = \frac{(0.81\ ft^2)(6.1\ in)(50\ in/in)(2\ rows)}{(12\ in/ft)}$$

$$\boxed{V = 41\ FT^3}$$

25 PASSENGER OVERHEAD VOLUME

$$V = \frac{(0.81\ ft^2)(4.3\ in)(50\ in/in)(2\ rows)}{(12\ in/ft)}$$

$$\boxed{V = 29\ FT^3}$$

FIGURE A.1 LISTS THE OVERHEAD VOLUME PER PASSENGER OF THE 25, 36 AND 50 PASSENGER COMMUTERS ALONG WITH THE VALUES FOR OTHER COMMUTER AIRPLANES FOR COMPARISON.

TABLE A.1 COMPARISON OF CABIN AND BAGGAGE VOLUMES

Airplane Type	Number of Passengers	Overhead Baggage Volume (cuft)	Overhead Volume per Seat (cuft)
NASA			
50	50	56	1.1
36	36	41	1.1
25	25	29	1.2
British Aerospace			
BAe Super 748	46	41	0.85
BAe ATP	48	100	1.6
BAe 146-100	64	56	0.68
de Havilland			
DASH 7	50	59	1.2
DASH 8	37	32	0.86
Fokker			
F-27	52	40	0.77
50	50	79	1.6
F-28	65	107	1.6
Shorts			
330	30	40	1.3
360	36	52	1.4
ATR Consortium			
ATR 42-200	46	53	1.2
Embraer			
EMB-120	30	32	1.1

A.2 COCKPIT LAYOUT

This section contains the flight deck layout for the

family of transports.

Figure 2.2 contains the common flight deck layout for the family of commuter transports. Figure 2.2 also shows the laminar flow nose shape used to enclose the flight deck.

The cockpit is designed using figure 2.21 of Reference (3). The cockpit includes a third seat to accomodate an observer, possibly FAA. The fuselage nose is designed similar to the Piaggio P-180 business airplane.

Jane's all the World Aircraft (years '83, '84) gives information on the avionics for these airplanes, Boeing: 737-200, 747, 757, 767; MD-80; DHC-8 Dash 8; BAe: 146-200, 748; Fokker: 100, 50; Airbus: A310, A300. Learjet advertising information on the model 55 provides a list of avionics for this 10 passenger airplane. Business and Commercial Aviation, April 1985, contains a section detailing circa 1985 avionics components and information for these systems.

From the above resources the following list of avionics has been chosen for the common flight deck of the family of commuter transports being developed. This list is not meant to be a final listing. The components are:

- Dual Navigation
- Dual Communications
- Dual Airspeed Indicators
- Dual RDMI
- Dual Instrument Switching Panel
- Dual EHSI
- Dual Clock
- Dual EIACS
- Dual Altimeter
- Dual Vertical Velocity Indicators
- Dual VOR
- Dual ILS
- Dual Artificial Horizons
- Dual Directional Gyros
- Dual RMI
- Dual Airdata Computer Systems
- Flight Recorder
- Flight Voice Recorder
- Flight Managment Computer System
- Auto Pilot
- Colour Weather Radar
- Dual EADI
- Dual DME

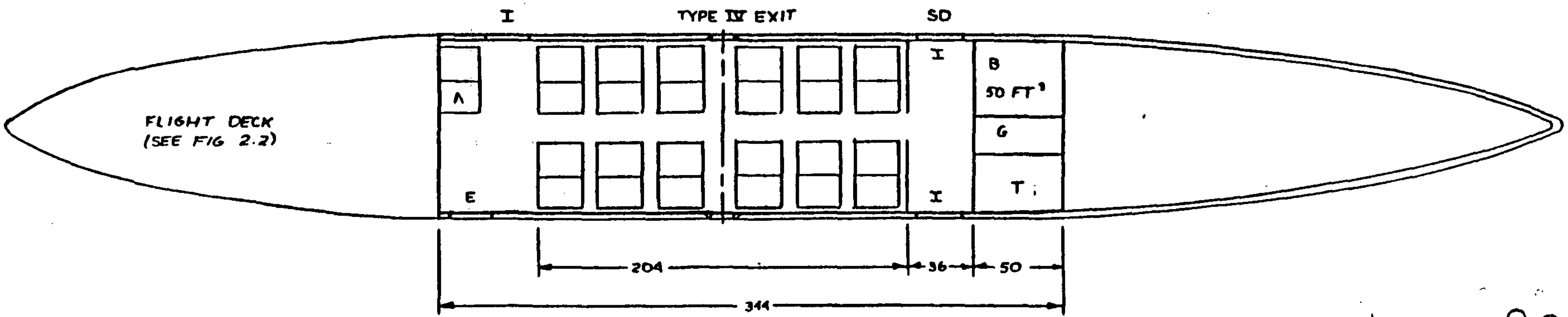
A.3 CABIN LAYOUTS

The cabin layouts presented in this section were 'laid out' using the methods presented in References (2) and (3). The seat pitch chosen was 32 inches which is consistent with those of other commuter airplanes as shown in Reference (8).

Figure A.2 presents the cabin layout for the 25-passenger commuter.

Figure A.3 presents the cabin layout for the 36-passenger commuter along with an alternate cockpit layout having 3 passenger seats to be used as the second cockpit on a twin body 75-passenger commuter.

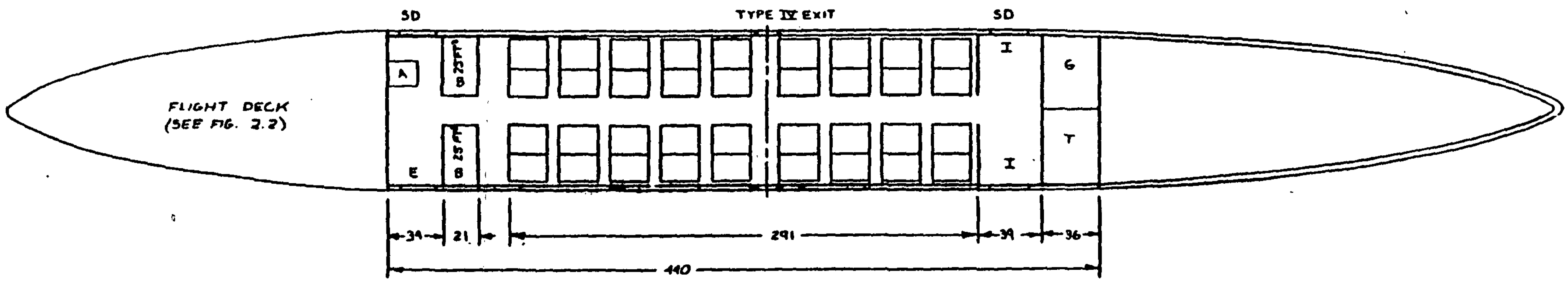
Figure A.4 presents the cabin layout for the 50-passenger commuter.



A: ATTENDANT SEAT
B: BAGGAGE COMPARTMENT
E: ENTRANCE DOOR
G: GALLEY
I: EMERGENCY DOOR
SD: SERVICE DOOR
T: TOILET

FIGURE A.2: 25 PASSENGER CABIN LAYOUT

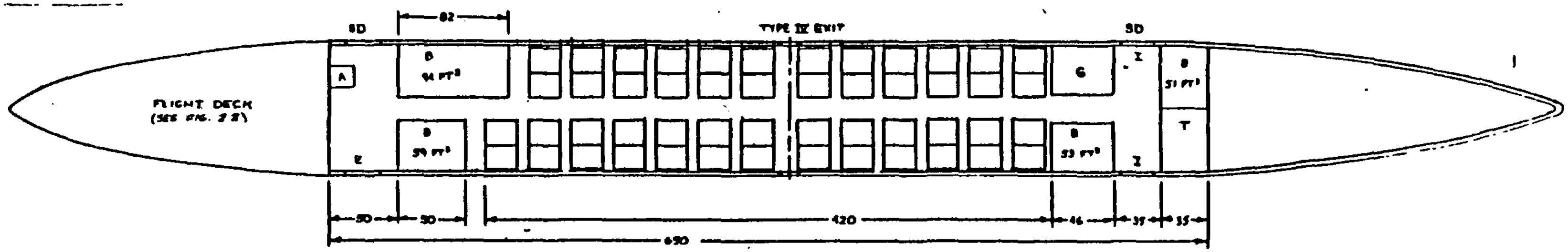
SCALE: 1:50 INCHES



A: ATTENDANT SEAT
B: BAGGAGE COMPAR
E: ENTRANCE DOOR
G: GALLEY
I: EMERGENCY DOOR
SD: SERVICE DOOR

FIGURE A.3: 36 PASSENGER CABIN LAYOUT

SCALE: 1:50 INCHES



A: ATTENDANT SEAT
B: BAGGAGE COMPARTMENT
E: ENTRANCE DOOR
G: GALLEY
I: EMERGENCY DOOR
SD: SERVICE DOOR
T: TOILET

FIGURE A.11 50 PASSENGER CABIN LAYOUT

SCALE: 1:50 INCHES

Appendix B

Airplane component weight, center of gravity and inertia breakdowns.

Item	25 pax	Mom. Arm			Moment			I-xx	I-xx
		Xi	Yi	Zi	Wi*Xi	Wi*Yi	Wi*Zi	(Woe)	(Wto)
Wing	2,899	595	176	170	1,724,905	510,224	492,830	2,846,809	2,836,708
Engine Mount Bar	267	599	76	205	159,933	20,292	54,735	48.784	49.228
Vertical Tail	340	860	0	343	292,400	0	116,620	231,862	239,328
Horizontal Tail	200	941	0	431	188,200	0	86,200	346,564	353,564
Fuselage	2,158	478	0	195	1,031,524	0	420,810	1	416
Accustic Treatment	1,585	646	0	195	1,023,910	0	309,075	1	306
Main Gear	1,438	615	90	130	884,370	129,420	186,940	550,134	536,665
Nose Gear	331	226	0	130	74,806	0	43,030	43,299	40,199
Structural Weight	9,218	584		186	5,380,048	659,936	1,710,240		
Powerplant Weight	5,434	671	130	215	3,646,214	706,420	1,168,310	2,922,715	2,939,743
Engine Controls	34	175	0	210	5,950	0	7,140	242	323
Engine Starting Sys.	27	671	130	210	18,117	3,510	5,670	14,374	14,439
Fuel System	464	589	176	170	273,296	81,664	78,880	455,647	454,030
Flight Controls	429	561	0	185	240,669	0	79,365	1,300	752
Hydraulics/Pneumatic	189	358	0	160	67,662	0	30,240	7,145	6,208
Electrical System	735	560	0	185	411,600	0	135,975	2,228	1,288
Avionics	445	153	0	190	68,085	0	84,550	329	87
A/C - Pressurization	535	645	0	180	345,075	0	96,300	3,679	2,602
Oxygen System	66	290	0	220	19,140	0	14,520	1,295	1,550
Furnishings	1,358	461	0	200	626,038	0	271,600	1,109	2,368
APU	60	831	0	215	49,860	0	12,900	755	943
Paint	105	491	0	200	51,555	0	21,000	86	183
Fixed Equipment Wt.	4,447	490		188	2,177,047	85,174	838,140		
Empty Weight	19,099	587		195	11,203,309	1,451,530	3,716,690		
Trapped Fuel / Oil	105	589	176	170	61,845	18,480	17,850	103,110	102,744
Stewardesses	0	302	0	200	0	0	0	0	0
Pilots	410	180	0	214	73,800	0	87,740	4,661	5,885
Operating Wt. Empty	19,614	578		195	11,338,954	1,470,010	3,822,280	9,580,067	
Fuel	3,767	589	176	170	2,218,763	662,992	640,390		3,686,057
Passengers	5,125	531	0	200	2,721,375	0	1,025,000		8,938
Take-off Weight	28,506	571		193	16,279,092	2,133,002	5,487,670		14,943,977
OWE + Pax	24,739	568		196	14,060,329		4,847,280		
OWE + Fuel	23,381	580		191	13,557,717		4,462,670		
Excursion									
Empty Wt.	19,099	587		195	11,203,309		3,716,690		Component Inertias:
OWE	19,614	578		195	11,338,954		3,822,280		
+ Fuel	23,381	580		191	13,557,717		4,462,670		
+ Pasengers	28,506	571		193	16,279,092		5,487,670		
- Fuel	24,739	568		196	14,060,329		4,847,280		
- Passengers	19,614	578		195	11,338,954		3,822,280		
Travel		12							
Gear		615							
Aft C.G.		587							
Fwd C.G.	568	0.149		12					

Le Z c- 555

Aft C.G.	580	0.278
X-ac-h bar		4.150
l-v		20.678
X-ac-mb bar		0.257

25 Passenger Airplane

Summary of Inertias:
(slug-ft^2)

ORIGINAL PAGE IS
OF POOR QUALITY

I-yy (Woe)	I-yy (Wto)	I-zz (Woe)	I-zz (Wto)
81,472	97,224	2,816,775	2,842,627
4,474	7,766	51,556	54,404
1,071,609	1,121,475	839,747	882,147
1,165,212	1,204,212	818,628	850,648
672,140	581,477	672,139	581,061
227,091	276,851	227,090	276,545
248,949	260,870	422,865	448,255
1,318,761	1,265,245	1,275,462	1,225,046
1,525,869	1,771,808	4,311,776	4,540,687
171,958	166,103	171,716	165,780
7,434	8,636	21,424	22,561
10,635	11,940	448,435	451,356
5,202	2,106	3,901	1,354
291,733	272,910	284,588	266,702
9,716	4,091	7,488	2,803
2,499,797	2,417,581	2,499,468	2,417,494
78,090	93,472	74,411	90,870
171,566	163,614	170,271	162,064
579,933	513,791	578,824	511,423
120,024	126,934	119,269	125,991
24,847	21,109	24,761	20,926
2,407	2,702	101,478	102,139
0	0	0	0
2,024,303	1,954,837	2,019,642	1,948,952
17,507,196		24,380,695	
	96,937		3,664,351
	264,771		255,833
	18,993,010		27,128,487

ertias:	I-xx	I-yy	I-zz
Fuselage	584,679	4,143,333	4,143,333
Wing	1,202,585	76,147	1,276,659
Vertical Tail	30,269	42,825	12,809
Horizontal Tail	37,787	1,585	39,335
Engine Mount	3,486	10,059	13,346
Engines	103,545	614,851	614,851
Furnishings	28,156	271,642	288,528
Fuel	1,562,655	98,947	1,658,909
Passengers	106,260	1,025,159	1,088,883

r Airplane

nertias: 2)		W-oe	W-to
	I-xx	66,528	103,778
	I-yy	121,578	131,896
	I-zz	169,310	188,392
Weight Used		19,614	28,506
C.G. Location		578	571

ORIGINAL PAGE IS
OF POOR QUALITY

Item	36 pax		Mom. Arm			Moment		I-xx	I-xx
		Xi	Yi	Zi	Wi*Xi	Wi*Yi	Wi*Zi	(Woe)	(Wto)
Wing	2,899	633	176	170	1,835,067	510,224	492,830	2,845,053	2,833,624
Engine Mount Bar	267	695	76	205	185,565	20,292	54,735	48,851	49,382
Vertical Tail	340	956	0	343	325,040	0	116,620	233,100	241,632
Horizontal Tail	200	1,037	0	431	207,400	0	86,200	347,744	355,710
Fuselage	3,575	539	0	195	1,926,925	0	697,125	30	1,147
Accustical Treatment	1,585	742	0	195	1,176,070	0	309,075	13	509
Main Gear	1,438	653	90	130	939,014	129,420	186,940	547,852	532,651
Nose Gear	331	226	0	130	74,806	0	43,030	42,774	39,275
Structural Weight	10,635	627		187	6,669,887	659,936	1,986,555		
Powerplant Weight	5,434	767	130	215	4,167,878	706,420	1,168,310	2,925,425	2,945,321
Engine Controls	37	175	0	210	6,475	0	7,770	277	381
Engine Starting Sys.	27	767	130	210	20,709	3,510	5,670	14,384	14,461
Fuel System	464	627	176	170	290,928		78,880	455,366	453,568
Flight Controls	729	630	0	185	459,270	0	134,865	2,036	1,044
Hydraulics/Pneumatic	283	404	0	160	114,332	0	45,280	10,457	8,887
Electrical System	846	630	0	185	532,980	0	156,510	2,363	1,211
Avionics	555	153	0	190	84,915	0	105,450	346	55
A/C - Pressurization	878	741	0	180	650,598	0	158,040	5,722	3,791
Oxygen System	82	290	0	220	23,780	0	18,040	1,660	2,029
Furnishings	1,995	509	0	200	1,015,455	0	399,000	1,889	4,183
APU	60	927	0	215	55,620		12,900	785	1,005
Paint	157	477	0	200	74,889	0	31,400	149	329
Fixed Equipment Wt.	6,113	545		189	3,329,951	3,510	1,153,805		
Empty Weight	22,182	639		194	14,167,716	1,369,866	4,308,670		
Trapped Fuel / Oil	157	627	176	170	98,439	27,632	26,690	154,078	153,470
Stewardesses	205	302	0	200	61,910		41,000	194	430
Pilots	410	180	0	214	73,800	0	87,740	4,855	6,288
Operating Wt. Empty	22,954	627		194	14,401,865	1,397,498	4,464,100	10,038,212	
Fuel	5,620	627	176	170	3,523,740	989,120	955,400		5,493,651
Passengers	7,380	584	0	200	4,309,920	0	1,476,000		15,473
Take-off Weight	35,954	618		192	22,235,525	2,386,618	6,895,500		18,031,680
OWE + Pax	30,334	617		196	18,711,785		5,940,100		
OWE + Fuel	28,574	627		190	17,925,605		5,419,500		
Excursion									
Empty Wt.	22,182	639		194	14,167,716		4,308,670		Component Inertias:
OWE	22,954	627		194	14,401,865		4,464,100		
+ Fuel	28,574	627		190	17,925,605		5,419,500		
+ Pasengers	35,954	618		192	22,235,525		6,895,500		
- Fuel	30,334	617		196	18,711,785		5,940,100		
- Passengers	22,954	627		194	14,401,865		4,464,100		
Travel		11							
Gear		653							
Aft C.G.		639							
Fwd C.G.	617	0.267		11					

36 Passenger Airpla

Summary of Inertias:
(slug-ft^s)

Aft C.G.	627	0.385
X-ac-h bar		4.754
l-v		24.715
X-ac-mb bar		0.906

ORIGINAL PAGE IS
OF POOR QUALITY

I-yy (Woe)	I-yy (Wto)	I-zz (Woe)	I-zz (Wto)
56,800	61,861	2,793,858	2,810,147
38,815	50,086	85,830	96,570
1,374,002	1,445,742	1,140,902	1,204,110
1,390,533	1,444,722	1,042,789	1,089,012
868,791	702,425	868,761	701,278
646,739	752,571	646,725	752,063
215,065	223,997	391,264	415,397
1,700,555	1,623,722	1,657,781	1,584,447
3,361,471	3,818,330	6,144,668	6,581,631
235,666	226,520	235,389	226,138
16,551	18,798	30,531	32,702
8,645	7,901	446,726	447,779
2,187	4,070	150	3,026
449,530	413,378	439,073	404,490
2,538	4,723	175	3,512
3,882,915	3,737,048	3,882,569	3,736,993
357,745	413,675	352,023	409,884
291,833	276,964	290,174	274,935
871,468	746,893	869,579	742,710
168,150	178,553	167,365	177,548
110,562	97,954	110,414	97,625
2,925	2,673	151,155	151,511
674,947	638,461	674,753	638,031
2,555,883	2,455,952	2,551,028	2,449,664
29,943,311		36,863,836	
	95,700		5,423,527
	287,600		272,127
	34,183,041		48,857,935

ertias:	I-xx	I-yy	I-zz
Fuselage	968,595	8,842,041	8,842,041
Wing	1,202,585	76,147	1,276,659
Vertical Tail	30,269	42,825	12,809
Horizontal Tail	37,787	1,585	39,335
Engine Mount	3,486	10,059	13,346
Engines	103,545	614,851	614,851
Furnishings	41,364	1,008,787	1,033,592
Fuel	2,331,330	147,619	2,474,931
Passengers	153,014	3,708,811	3,823,514

r Airplane

nertias: s)		W-oe	W-to
	I-xx	69,710	125,220
	I-yy	207,940	237,382
	I-zz	255,999	339,291
Weight Used		22,954	35,954
C.G. Locations		627	618

Item	50 pax	Nom. Arm			Moment			I-xx	I-xx
		Xi	Yi	Zi	Wi*Xi	Wi*Yi	Wi*Zi	(Woe)	(Wto)
Wing	2,899	732	176	170	2,122,068	510,224	492,830	2,844,074	2,833,620
Engine Mount Bar	267	905	76	205	241,635	20,292	54,735	48,891	49,393
Vertical Tail	340	1,166	0	343	396,440	0	116,620	233,801	241,798
Horizontal Tail	200	1,247	0	431	249,400	0	86,200	348,400	355,864
Fuselage	5,278	628	0	195	3,314,584	0	1,029,210	90	1,749
Accustic Treatment	1,585	952	0	195	1,508,920	0	309,075	27	525
Main Gear	1,438	752	90	130	1,081,376	129,420	186,940	546,568	532,363
Nose Gear	331	226	0	130	74,806	0	43,030	42,476	39,209
Structural Weight	12,338	729		188	8,989,229	659,936	2,318,640		
Powerplant Weight	5,434	977	130	215	5,309,018	706,420	1,168,310	2,926,980	2,945,729
Engine Controls	37	175	0	210	6,475	0	7,770	285	384
Engine Starting Sys.	27	977	130	210	26,379	3,510	5,670	14,390	14,462
Fuel System	464	726	176	170	336,864		78,880	455,209	453,536
Flight Controls	873	700	0	185	611,100	0	161,505	2,325	1,231
Hydraulics/Pneumatic	379	615	0	160	233,085	0	60,640	13,824	11,863
Electrical System	944	700	0	185	660,800	0	174,640	2,514	1,331
Avionics	658	153	0	190	100,674	0	125,020	371	62
A/C - Pressurization	1,092	951	0	180	1,038,492	0	196,560	6,899	4,674
Oxygen System	102	290	0	220	29,580	0	22,440	2,101	2,533
Furnishings	2,535	614	0	200	1,556,490	0	507,000	2,598	5,383
APU	60	1,137	0	215	68,220		12,900	802	1,009
Paint	210	583	0	200	122,430	0	42,000	215	446
Fixed Equipment Wt.	7,381	649		189	4,790,589	3,510	1,395,025		
Empty Weight	25,153	759		194	19,088,836	1,369,866	4,881,975		
Trapped Fuel / Oil	210	726	176	170	152,460	36,960	35,700	206,021	205,264
Stewardesses	205	302	0	200	61,910		41,000	210	435
Pilots	410	180	0	214	73,800	0	87,740	4,967	6,317
Operating Wt. Empty	25,978	746		194	19,377,006	1,406,826	5,046,415	10,564,272	
Fuel	6,913	726	176	170	5,018,838	1,216,688	1,175,210		6,757,094
Passengers	10,250	732	0	200	7,503,000	0	2,050,000		21,764
Take-off Weight	43,141	739		192	31,898,844	2,623,514	8,271,625		20,428,490
OWE + Pax	36,228	742		196	26,880,006		7,096,415		
OWE + Fuel	32,891	742		189	24,395,844		6,221,625		
Excursion									
Empty Wt.	25,153	759		194	19,088,836		4,881,975		Component Inertias:
OWE	25,978	746		194	19,377,006		5,046,415		
+ Fuel	32,891	742		189	24,395,844		6,221,625		
+ Pasengers	43,141	739		192	31,898,844		8,271,625		
- Fuel	36,228	742		196	26,880,006		7,096,415		
- Passengers	25,978	746		194	19,377,006		5,046,415		
Travel		6							
Aft		759							
Gear		752							
Fwd C.G.	739	0.530		6					

Aft C.G.	746	0.603
X-ac-h bar		6.040
L-v		32.342
X-ac-mb bar		-2.148

50 Passenger Airplane

Summary of Inertias:
(slug-ft^2)

I-yy (Woe)	I-yy (Wto)	I-zz (Woe)	I-zz (Wto)
70,429	47,511	2,808,466	2,796,002
211,018	229,012	257,993	275,484
2,098,797	2,164,877	1,864,996	1,923,079
1,909,292	1,957,460	1,560,891	1,601,595
2,280,414	2,037,876	2,280,323	2,036,127
2,092,586	2,226,980	2,092,559	2,226,455
186,206	177,424	363,688	369,111
2,823,239	2,750,960	2,780,761	2,711,752
9,092,786	9,625,405	11,874,428	12,388,297
375,101	366,724	374,816	366,340
45,026	47,652	59,001	61,554
14,197	9,406	452,434	449,316
59,492	43,371	57,167	42,141
215,669	194,185	201,845	182,321
64,331	46,899	61,816	45,568
7,189,638	7,032,762	7,189,267	7,032,700
1,434,630	1,524,213	1,427,731	1,519,539
661,025	642,826	658,924	640,293
1,373,374	1,244,551	1,370,776	1,239,169
286,049	295,804	285,247	294,794
173,420	160,121	173,205	159,675
6,426	4,257	204,766	203,354
1,255,720	1,219,493	1,255,510	1,219,058
4,085,897	3,994,157	4,080,930	3,987,840
58,848,475		65,824,307	
	140,133		6,694,227
	39,252		17,488
	67,033,444		83,526,675

ertias:	I-xx	I-yy	I-zz
Fuselage	1,429,998	18,172,923	18,172,923
Wing	1,202,585	76,147	1,276,659
Vertical Tail	30,269	42,825	12,809
Horizontal Tail	37,787	1,585	39,335
Engine Mount	3,486	10,059	13,346
Engines	103,545	614,851	614,851
Furnishings	52,560	1,925,323	1,956,843
Fuel	2,867,702	181,582	3,044,342
Passengers	212,519	7,784,838	7,912,286

r Airplane

nertias:		W-oe	W-to
2)			
	I-xx	73,363	141,865
	I-yy	408,670	465,510
	I-zz	457,113	580,046
Weight Used		25,978	43,141
C.G. Locations		746	739

Item	75 pax		Mom. Arm			Moment		I-xx	I-xx
		Xi	Yi	Zi	Wi*Xi	Wi*Yi	Wi*Zi	(Woe)	(Wto)
Wing	4,349	628	465	170	2,731,172	2,022,285	739,330	19,649,535	19,583,533
Engine Mount Bar	488	689	189	215	336,232		104,920	541,858	543,821
Vertical Tail	680	956	289	343	650,080	196,520	233,240	2,122,238	2,176,793
Horizontal Tail	1,027	1,024	0	431	1,051,648	0	442,637	1,516,549	1,652,749
Fuselage	7,150	539	289	195	3,853,850	2,066,350	1,394,250	18,633,046	18,576,679
Accustic Treatment	3,170	742	289	195	2,352,140	916,130	618,150	8,261,085	8,236,094
Main Gear	2,876	660	289	130	1,898,160	831,164	373,880	8,082,109	7,948,141
Nose Gear	662	226	289	130	149,612	191,318	86,060	1,860,346	1,829,509
Structural Weight	20,402	638		196	13,022,894	6,223,767	3,992,467		
Powerplant Weight	12,196	774	120	265	9,439,704	1,463,520	3,231,940	6,482,303	6,894,418
Engine Controls	44	175	289	210	7,700	12,716	9,240	114,233	114,279
Engine Starting Sys.	91	774	135	210	70,434	12,285	19,110	51,573	51,668
Fuel System	666	616	465	170	410,256		113,220	4,514,174	4,499,011
Flight Controls	1,458	630	289	185	918,540	421,362	269,730	3,820,451	3,800,276
Hydraulics/Pneumatic	546	404	289	160	220,584	157,794	87,360	1,465,094	1,449,413
Electrical System	1,103	630	289	185	694,890	318,767	204,055	2,890,231	2,874,969
Avionics	843	153	289	190	128,979	243,627	160,170	2,202,255	2,193,099
A/C - Pressurization	1,755	741	289	180	1,300,455	507,195	315,900	4,615,344	4,585,836
Oxygen System	164	290	289	220	47,560	47,396	36,080	425,978	427,126
Furnishings	3,969	509	289	200	2,020,221	1,147,041	793,800	10,324,137	10,304,661
APU	120	927	289	215	111,240		25,800	311,524	312,007
Paint	314	477	289	200	149,778	90,746	62,800	816,775	815,234
Fixed Equipment Wt.	11,073	549		189	6,080,637	2,958,929	2,097,265		
Empty Weight	43,671	654		213	28,543,235	10,646,216	9,321,672		
Trapped Fuel / Oil	313	616	465	170	192,808	145,545	53,210	2,121,526	2,114,400
Stewardesses	410	302	289	200	123,820		82,000	1,066,489	1,064,477
Pilots	410	180	289	214	73,800	118,490	87,740	1,064,338	1,065,743
Operating Wt. Empty	44,804	646		213	28,933,663	10,910,251	9,544,622	109,631,193	
Fuel	11,240	616	465	170	6,923,840	5,226,600	1,910,800		37,964,627
Passengers	15,375	584	289	200	8,979,000	4,443,375	3,075,000		39,917,906
Take-off Weight	71,419	628		203	44,836,503	20,580,226	14,530,422		195,191,465
OWE + Pax	60,179	630		210	37,912,663		12,619,622		
OWE + Fuel	56,044	640		204	35,857,503		11,455,422		Component Inert
Excursion ,									
Empty Wt.	43,671	654		213	28,543,235		9,321,672		
OWE	44,804	646		213	28,933,663		9,544,622		
+ Fuel	56,044	640		204	35,857,503		11,455,422		
+ Pasengers	71,419	628		203	44,836,503		14,530,422		
- Fuel	60,179	630		210	37,912,663		12,619,622		
- Passengers	44,804	646		213	28,933,663		9,544,622		
Travel		18							
Gear		660							
Aft C.G.		654							
Fwd C.G.	628	0.602							

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Aft C.G.	646	0.769
X-ac-h bar		4.283
l-v		23.185
X-ac-b bar		0.994

75 Passenger T

Summary of Iner

I-yy (Woe)	I-yy (Wto)	I-zz (Woe)	I-zz (Wto)
195,333	100,840	19,511,191	19,482,700
28,387	58,840	570,128	598,617
2,390,940	2,688,207	3,799,148	4,041,860
6,082,670	6,663,524	4,566,121	5,010,775
2,606,241	1,768,063	21,094,793	20,312,983
944,163	1,292,100	9,141,185	9,514,113
634,322	574,996	7,483,922	7,558,564
3,767,640	3,432,728	5,344,287	5,040,211
7,255,438	9,538,712	11,690,174	13,561,332
303,115	280,441	417,323	394,603
46,523	60,580	98,044	112,006
56,690	26,046	4,494,207	4,478,725
46,894	15,651	3,796,134	3,785,066
1,039,787	881,984	2,409,433	2,267,312
35,476	11,840	2,871,835	2,863,462
6,376,488	5,911,309	8,550,948	8,094,924
554,051	729,044	5,050,372	5,254,872
645,470	583,024	1,070,952	1,007,359
2,328,971	1,742,370	12,611,215	12,044,089
294,972	334,395	606,467	645,408
279,681	222,038	1,093,142	1,037,039
26,643	12,241	2,112,142	2,104,866
1,508,242	1,352,746	2,570,404	2,416,921
2,764,700	2,556,692	3,829,014	3,619,600
63,540,242		162,019,371	
	219,783		37,793,448
	922,262		40,828,771
	72,853,682		256,191,887

36 Pax Wing Wt.	2,899
36 Pax Fuel Wt.	5,620

ertias:	I-xx	I-yy	I-zz
Fuselage	1,937,190	17,684,081	17,684,081
Outbd. Wing	1,202,585	76,147	1,276,659
Center Wing	1,255,690	64,319	1,318,342
Vertical Tail	60,538	85,650	25,619
Horizotal Tail	1,610,478	13,217	1,623,311
Engine Mount	16,671	20,630	36,816
Engines	512,558	2,750,829	2,750,829
Furnishings	82,292	2,006,954	2,056,305
Outbd. Fuel	2,331,330	147,619	2,474,931
Center Fuel	4,866,882	249,293	5,109,710
Passengers	318,779	7,774,483	7,965,655

r Twin-body Airplane

nertias:	W-oe	W-to
I-xx	761,328	1,355,496
I-yy	441,252	505,928
I-zz	1,125,135	1,779,110
Weight Used	44,804	71,419
C.G. Location	646	628

Item	100 pax		Mom. Arm			Moment		I-xx	I-xx
		Xi	Yi	Zi	Wi*Xi	Wi*Yi	Wi*Zi	(Woe)	(Wto)
Wing	4,349	752	465	170	3,270,448	2,022,285	739,330	19,631,691	19,571,863
Engine Mount Bar	488	899	189	215	438,712		104,920	542,084	544.581
Vertical Tail	680	1,166	289	343	792,880	196,520	233,240	2,135.355	2,188,647
Horizontal Tail	1,027	1,234	0	431	1,267,318	0	442,637	1,549,654	1,681,862
Fuselage	10,556	628	289	195	6,629,168	3,050,684	2,058,420	27,482,994	27,416,172
Accustic Treatment	3,170	952	289	195	3,017,840	916,130	618,150	8,253,229	8,233,163
Main Gear	2,876	784	289	130	2,254,784	831,164	373,880	8,047,485	7,922,294
Nose Gear	662	226	289	130	149,612	191,318	86,060	1,852,377	1,823,560
Structural Weight	23,808	749			17,820,762	7,208,101	4,656,637		
Powerplant Weight	12,196	984	135	265	12,000,864	1,646,460	3,231,940	8,027,571	8,438,948
Engine Controls	44	175	289	210	7,700	12,716	9,240	114,221	114,320
Engine Starting Sys.	91	984	135	210	89,544	12,285	19,110	51,548	51,753
Fuel System	666	740	465	170	492,840		113,220	4,510,075	4,496,330
Flight Controls	1,746	700	289	185	1,222,200	504,594	323,010	4,568,213	4,547,168
Hydraulics/Pneumatic	726	615	289	160	446,490	209,814	116,160	1,942,556	1,923,418
Electrical System	1,253	700	289	185	877,100	362,117	231,805	3,278,334	3,263,231
Avionics	1,016	153	289	190	155,448	293,624	193,040	2,650,935	2,641,596
A/C - Pressurization	2,183	951	289	180	2,076,033	630,887	392,940	5,730,684	5,698,125
Oxygen System	204	290	289	220	59,160	58,956	44,880	530,119	531,747
Furnishings	4,952	614	289	200	3,040,528	1,431,128	990,400	12,872,480	12,855,303
APU	120	1,137	289	215	136,440		25,800	311,580	312,194
Paint	421	583	289	200	245,443	121,669	84,200	1,094,369	1,092,908
Fixed Equipment Wt.	13,422	659		190	8,848,926	3,637,790	2,543,805		
Empty Weight	49,426	782		211	38,670,552	12,492,351	10,432,382		
Trapped Fuel / Oil	420	740	465	170	310,800	195,300	71,400	2,844,191	2,835,523
Stewardesses	410	302	289	200	123,820		82,000	1,065,775	1,064,353
Pilots	410	180	289	214	73,800	118,490	87,740	1,064,467	1,066,330
Operating Wt. Empty	50,666	773		211	39,178,972	12,806,141	10,673,522	127,936,580	
Fuel	13,878	740	465	170	10,269,720	6,453,270	2,359,260		46,671,365
Passengers	20,500	732	289	200	15,006,000	5,924,500	4,100,000		53,217,631
Take-off Weight	85,044	758		201	64,454,692	25,183,911	17,132,782		237,149,960
OWE + Pax	71,166	761		208	54,184,972		14,773,522		
OWE + Fuel	64,544	766.		202	49,448,692		13,032,782		Component Inert
Excursion									
Empty Wt.	49,426	782		211	38,670,552		10,432,382		
OWE	50,666	773		211	39,178,972		10,673,522		
+ Fuel	64,544	766		202	49,448,692		13,032,782		
+ Pasengers	85,044	758		201	64,454,692		17,132,782		
- Fuel	71,166	761		208	54,184,972		14,773,522		
- Passengers	50,666	773		211	39,178,972		10,673,522		
Travel		15							
Gear		784							
Aft C.G.		782							
Fwd C.G.	758	0.659		15.381					

Aft C.G.	773	0.802
X-ac-h bar		4.942
l-v		30.060
X-ac-b bar		1.794

100 Passenger

Summary of Iner

I-yy (Woe)	I-yy (Wto)	I-zz (Woe)	I-zz (Wto)
189,795	92,301	19,523,496	19,485,831
240,018	304,763	781,532	843,781
3,629,785	3,943,410	5,024,875	5,285,209
8,325,144	8,917,304	6,775,490	7,235,442
7,005,224	5,549,738	34,327,208	32,938,544
3,171,226	3,716,156	11,376,104	11,941,101
591,905	517,341	7,476,128	7,526,755
6,296,581	5,926,229	7,881,197	7,539,662
17,950,776	20,909,025	23,740,082	26,286,954
489,504	464,757	603,724	578,878
125,590	144,798	177,136	196,139
57,155	27,116	4,498,771	4,482,477
327,153	196,614	4,823,878	4,714,384
623,223	499,554	2,449,936	2,345,406
234,778	141,098	3,461,809	3,383,232
12,163,122	11,558,700	14,787,088	14,192,005
2,206,811	2,561,246	7,809,896	8,196,890
1,481,439	1,390,302	2,010,453	1,917,689
3,922,266	3,187,357	16,759,738	16,042,006
493,485	536,713	804,925	847,538
475,250	400,293	1,566,643	1,493,146
36,044	17,100	2,837,063	2,826,787
2,831,770	2,648,616	3,894,646	3,712,914
4,485,501	4,257,807	5,549,685	5,320,128
94,083,758		209,590,674	
	281,458		46,527,568
	428,707		53,643,630
	110,854,136		334,963,372

50 Pax Wing Wt.	2,899
50 Pax Fuel Wt.	6,913

ertias:	I-xx	I-yy	I-zz
Fuselage	2,859,997	9,403,601	9,403,601
Outbd. Wing	1,202,585	76,147	1,276,659
Center Wing	1,255,690	64,319	1,318,342
Vertical Tail	60,538	85,650	25,619
Horizontal Tail	1,610,478	13,217	1,623,311
Engine Mount	16,671	20,630	36,816
Engines	512,558	2,750,829	2,750,829
Furnishings	102,673	3,761,026	3,822,599
Outbd. Fuel	2,867,702	181,582	3,044,342
Center Fuel	6,031,642	308,954	6,332,586
Passengers	425,039	15,569,677	15,824,573

er Twin-body Airplane

nertias:	W-oe	W-to
I-xx	888,448	1,646,875
I-yy	653,359	769,820
I-zz	1,455,491	2,326,135
Weight Used	50,666	85,044
C.G. Location	773	758

Appendix C

Stability and Control Calculation

Purpose:
a) Calculation of airplane lift curve
b) Calculation of airplane pitching moment curve
c) Short period frequency and damping
d) Dutch roll frequency and damping
e) One-engine out sizing
f) Take-off rotation requirement

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25 Passenger Airplane: Calculations for Cruise and M.C. at Fwd and Aft C.G.

Note: All Results in RADIANS

Cruise Mach Number	0.700		
Section Lift Curve Slope	6.000	Forward C.G.	0.145
Wing-Body ac shift	-0.090	Aft C.G.	0.280
X-bar C.G.	0.280		
Min Control Dynamic Pres.	51.170	Cruise A.C.	0.369
Cruise Dynamic Pressure	215.600	Min Cntrl A.C.	0.376
Minimum Control Speed fps	207.500		
Cruise Speed fps	696.290	Static Margin	-0.089 -0.224
1/rad to 1/deg conversion	0.017		

Moments of Inertia:	Fwd C.G.	Aft C.G.
I-xx	67,265	102,964
I-yy	130,433	122,535
I-zz	177,066	180,634
Weights	24,739	23,381

Fuselage:

Fuselage Height	8.050
Fuselage Width	8.050
Fuselage Length	71.330
C-n-B-body	-0.171

Wing:

Wing Area sqft	592.000
Wing Span ft	84.300
Wing MGC ft	7.450
Aspect Ratio	12.000
Leading Edge Sweep rad	0.262
Semichord Sweep rad	0.194
C-L-o	0.170
C-m-o-wing (cruise)	-0.054
C-m-o-wing (approach)	-0.045

Wing Lift Curves:

K:1.0544	C-L-a (cruise)	4.7089
k:0.6820	C-L-a (app)	4.7794
B:0.7141		

Horizontal Tail:

Total H.T. Area sqft	120.000
H.T. Area (each) sqft	120.000
H.T. Span ft	26.569
H.T. Root Chord	6.022
H.T. MGC ft	4.684
H.T. Aspect Ratio	5.883
H.T. LE Sweep rad	0.436
H.T. c/2 Sweep rad	0.314
H.T. Taper Ratio	0.500
H.T. X-ac-h bar	4.150
1 - downwash	0.746
H.T. q-bar corr. (eta-h)	1.000
Elevator effectiveness te	0.540

Horizontal Tail Lift Curves:

K:1.0630	C-L-a (cruise)	3.8395
k:0.6820	C-L-a (app)	3.9610
B:0.71		

Vertical Tail:

Total V.T. Area sqft	170.000
V.T. Area (each) sqft	170.000
V.T. Span ft	15.400
V.T. MGC ft	12.000
V.T. Aspect Ratio	1.40
V.T. Effective Asp. Ratio	1.960

Vertical Tail Lift Curves:

K:1.0366	C-L-a (cruise)	2.0802
k:0.68	C-L-a (app)	2.2314
B:0.71		

V.T. LE Sweep rad	0.785
V.T. c/2 Sweep rad	0.687
V.T. Taper Ratio	0.330
V.T. Moment Arm l-v	20.678
Approach Alpha α (rad)	0.1745
Approach V.T. l-v	22.17
1+(dσ/dβ)	1.477

Engine Mounting Bar:	
Bar Area sqft	112.000
Bar Span ft	11.000
Bar MGC ft	10.200
Bar Aspect Ratio	1.080
Bar LE Sweep rad	0.436
Bar c/2 Sweep rad	0.281
Bar Taper Ratio	0.880
X-bar ac-h	0.257
1 - downwash	1.000
Bar q-bar corr. (eta-h)	1.000

Engine Bar Lift Curves:

K:1.0202		C-L-α (cruise)	1.5317
k:0.68		C-L-α (app)	1.5395
β:0.71			

Total Take-off Thrust lbs	13,325
Total Cruise Thrust (lbs)	1,698
Z-T (vertical mom. arm)	1.920
Y-T (horizontal mom. arm)	10.500

Non-dim. Derivatives:	Cruise-fwd	Cruise-aft	Min Cntrl-fwd	Min Cntrl-aft
C-L-α Airplane	5.579	5.579	5.670	5.670
C-m-α Airplane	-1.251	-0.498	-1.308	-0.543
C-L-α-dot	1.583	1.530	1.634	1.578
C-m-α-dot	-6.342	-5.921	-6.542	-6.109
C-m-q	-27.472	-25.644	-28.341	-26.456
C-y-β	-1.168	-1.168	-1.232	-1.232
C-n-β	0.045	0.045	0.078	0.078
C-y-r	0.433	0.433	0.498	0.498
C-n-r	-0.106	-0.106	-0.131	-0.131

Dimensional Derivatives:	Cruise-fwd	Cruise-aft	Min Cntrl-fwd	Min Cntrl-aft
Z-α:	-926.009	-979.793	-223.337	-236.308
Z-α-dot:	-1.406	-1.437	-1.155	-1.181
M-α:	-9.121	-3.864	-2.264	-1.000
M-α-dot:	-0.247	-0.246	-0.203	-0.202
M-q:	-1.071	-1.065	-0.880	-0.875

Y-β:	-193.847	-205.106	-48.535	-51.354
Y-r:	4.349	4.601	3.983	4.215
N-β:	2.760	2.705	1.123	1.101
N-r:	-0.391	-0.383	-0.384	-0.376
Short Period:				
Frequency	3.247	2.316	1.792	1.413
Damping Ratio	0.408	0.587	0.603	0.784
N-a	28.785	30.457	6.832	7.229
Dutch Roll:				
Frequency	1.689	1.673	1.092	1.083
Damping Ratio	0.198	0.202	0.283	0.288
Omega * Zeta	0.334	0.339	0.309	0.312

Verify Class I Handling Qualities:

Short Period:				
Below max freq.	yes	yes	yes	yes
Above min freq.	yes	yes	yes	yes
Damping	yes	yes	yes	yes
Dutch Roll:				
Frequency	yes	yes	yes	yes
Damping Ratio	yes	yes	yes	yes
Omega * Zeta	yes	yes	yes	yes

Engine-Out Calculations:

C-y-δ-r	-0.324
C-n-δ-r	0.085
Required δ-r (rad)	0.402
Required δ-r (deg)	23.051

Lift and Pitching Moment Calculations:

Airplane X-ac (cruise)	0.369
Airplane X-ac (approach)	0.376
Airplane C-L-a (cruise)	5.579
Airplane C-L-a (approach)	5.670
Airplane C-M-a (cruise)	
Forward C.G.	-1.251
Aft C.G.	-0.498
Airplane C-M-a (approach)	
Forward C.G.	-1.308
Aft C.G.	-0.543
C-L-i-H (cruise)	0.778
C-L-i-H (approach)	0.803

C-L-δ-e	(cruise)	0.420	
C-L-δ-e	(approach)	0.434	
C-M-i-h	(cruise)		bar values
	Forward C.G.	-3.117	-2.942
	Aft C.G.	-3.012	-2.942
C-M-i-h	(approach)		
	Forward C.G.	-3.216	-3.030
	Aft C.G.	-3.107	-3.030
C-M-δ-e	(cruise)		
	Forward C.G.	-1.683	-1.589
	Aft C.G.	-1.626	-1.589
C-M-δ-e	(approach)		
	Forward C.G.	-1.736	-1.636
	Aft C.G.	-1.678	-1.636
Δf C-m-ac	(cruise)	-0.038	
	(approach)	-0.038	
C-m-ac-wb	(cruise)	-0.092	
	(approach)	-0.083	
C-m-o (a-ht)	(cruise)		
	Forward C.G.	-0.052	-0.014
	Aft C.G.	-0.029	-0.014
C-m-o (a-ht)	(approach)		
	Forward C.G.	-0.043	-0.004
	Aft C.G.	-0.020	-0.004
C-y-δ-r	(cruise)	-0.302	
	(approach)	-0.324	
C-n-δ-r	(cruise)	0.074	
	(approach)	0.085	

Lift Curve Equations:	Condition	C-l-o	α	i-h	δ-e	δ-flaps	
	Cruise	0.170	0.097	0.014	0.007	0.027	
	Min Control	0.170	0.099	0.014	0.008	0.072	
Pitching Moment Eqns:	**Condition**	**C-m-o**	**C-L**	**i-h**	**δ-e**	**C-m-δ-f**	**Thrust**
	Cruise-fwd	-0.014	-0.224	-0.051	-0.028		-0.003
	Cruise-aft	-0.014	-0.089	-0.051	-0.028		-0.003
	Min Cntrl-fw	-0.004	-0.231	-0.053	-0.029	-0.390	-0.113
	Min Cntrl-af	-0.004	-0.096	-0.053	-0.029	-0.390	-0.113
ΔC-m-o H.T.	Forward C.G.	0.138					
	Aft C.G.	0.133					

Take-off Rotation Calculations:

Take-off Thrust T	13,325	
Thrust Moment Arm z-t	1.92	
Drag at T-O D	2,000.00	
Drag Moment Arm z-d	2.00	
Lift at T-O	5,000	
Take-off Weight W-to	24,739	
X-mg	5.00	
X-cg	1.33	
Z-mg	7.75	
X-ac-wb	1.19	
X-ac-h	30.92	
Wheel-ground friction μ	0.02	
q-bar T.O.R.	50.00	
C-l-o-h	0.17	
C-m-ac-wb	-0.08	
H.T. incidence for rotat.	0.15	rad
	8.88	deg
Elevator Deflection	16.44	deg

W_{TO} - W_{OE}

25 Passenger Airplane: Calculations for Cruise and M.C. at Fwd and Aft C.G.

Note: All Results in RADIANS

Cruise Mach Number	0.700			
Section Lift Curve Slope	6.000	fwd - W-to C.G.	0.179	
Wing-Body ac shift	-0.090	aft - W-oe C.G.	0.257	
X-bar C.G.	0.257			
Min Control Dynamic Pres.	51.170	Cruise A.C.	0.369	
Cruise Dynamic Pressure	215.600	Min Cntrl A.C.	0.376	
Minimum Control Speed fps	207.500			
Cruise Speed fps	696.290	Static Margin	-0.112	-0.190
1/rad to 1/deg conversion	0.017			

Moments of Inertia:	Fwd C.G.	Aft C.G.
I-xx	103,778	66,528
I-yy	131,896	121,578
I-zz	188,392	169,310
Weights	28,506	19,614

Fuselage:

Fuselage Height	8.050
Fuselage Width	8.050
Fuselage Length	71.330
C-n-β-body	-0.171

Wing:

Wing Area sqft	592.000
Wing Span ft	84.300
Wing MGC ft	7.450
Aspect Ratio	12.000
Leading Edge Sweep rad	0.262
Semichord Sweep rad	0.194
C-L-o	0.170
C-m-o-wing (cruise)	-0.054
C-m-o-wing (approach)	-0.045

Wing Lift Curves:

K:1.0544	C-L-α (cruise)	4.7089
k:0.6820.	C-L-α (app)	4.7794
β:0.7141		

Horizontal Tail:

Total H.T. Area sqft	120.000
H.T. Area (each) sqft	120.000
H.T. Span ft	26.569
H.T. Root Chord	6.022
H.T. MGC ft	4.684
H.T. Aspect Ratio	5.883
H.T. LE Sweep rad	0.436
H.T. c/2 Sweep rad	0.314
H.T. Taper Ratio	0.500
H.T. X-ac-h bar	4.150
1 - downwash	0.746
H.T. q-bar corr. (eta-h)	1.000
Elevator effectiveness τe	0.540

Horizontal Tail Lift Curves:

K:1.0630	C-L-α (cruise)	3.8395
k:0.6820	C-L-α (app)	3.9610
β:0.71		

Vertical Tail:

Total V.T. Area sqft	170.000
V.T. Area (each) sqft	170.000
V.T. Span ft	15.400
V.T. MGC ft	12.000
V.T. Aspect Ratio	1.40
V.T. Effective Asp. Ratio	1.960

Vertical Tail Lift Curves:

K:1.0366	C-L-α (cruise)	2.0802
k:0.68	C-L-α (app)	2.2314
β:0.71		

V.T. LE Sweep rad	0.785
V.T. c/2 Sweep rad	0.687
V.T. Taper Ratio	0.330
V.T. Moment Arm l-v	20.678
Approach Alpha s (rad)	0.1745
Approach V.T. l-v	22.17
1+(de/dB)	1.477

Engine Mounting Bar:

Bar Area sqft	112.000
Bar Span ft	11.000
Bar MGC ft	10.200
Bar Aspect Ratio	1.080
Bar LE Sweep rad	0.436
Bar c/2 Sweep rad	0.281
Bar Taper Ratio	0.880
X-bar ac-h	0.257
1 - downwash	1.000
Bar q-bar corr. (eta-h)	1.000

Engine Bar Lift Curves:

K:1.0202	C-L-s (cruise)	1.5317
k:0.68	C-L-s (app)	1.5395
B:0.71		

Total Take-off Thrust lbs	13,325
Total Cruise Thrust (lbs)	1,698
Z-T (vertical mom. arm)	1.920
Y-T (horizontal mom. arm)	10.500

Non-dim. Derivatives:	Cruise-fwd	Cruise-aft	Min Cntrl-fwd	Min Cntrl-aft
C-L-s Airplane	5.579	5.579	5.670	5.670
C-m-s Airplane	-1.061	-0.626	-1.116	-0.673
C-L-s-dot	1.570	1.539	1.620	1.588
C-m-s-dot	-6.234	-5.992	-6.432	-6.182
C-m-q	-27.003	-25.949	-27.858	-26.771
C-y-B	-1.168	-1.168	-1.232	-1.232
C-n-B	0.045	0.045	0.078	0.078
C-y-r	0.433	0.433	0.498	0.498
C-n-r	-0.106	-0.106	-0.131	-0.131

Dimensional Derivatives:	Cruise-fwd	Cruise-aft	Min Cntrl-fwd	Min Cntrl-aft
Z-s:	-803.639	-1,167.969	-193.823	-281.693
Z-s-dot:	-1.210	-1.724	-0.994	-1.416
M-s:	-7.652	-4.898	-1.909	-1.250
M-s-dot:	-0.240	-0.251	-0.198	-0.206
M-q:	-1.041	-1.086	-0.856	-0.892

Y-β:	-168.231	-244.498	-42.121	-61.217
Y-r:	3.774	5.485	3.457	5.024
N-β:	2.594	2.886	1.056	1.175
N-r:	-0.367	-0.408	-0.360	-0.401
Short Period:				
Frequency	2.976	2.592	1.646	1.569
Damping Ratio	0.409	0.581	0.604	0.783
N-α	24.981	36.306	5.929	8.617
Dutch Roll:				
Frequency	1.634	1.734	1.054	1.125
Damping Ratio	0.186	0.219	0.267	0.309
Omega * Zeta	0.304	0.380	0.282	0.348
Verify Class I Handling Qualities:				
Short Period:				
Below max freq.	yes	yes	yes	yes
Above min freq.	yes	yes	yes	yes
Damping	yes	yes	yes	yes
Dutch Roll:				
Frequency	yes	yes	yes	yes
Damping Ratio	yes	yes	yes	yes
Omega * Zeta	yes	yes	yes	yes

Engine-Out Calculations:

C-y-δ-r		-0.324
C-n-δ-r		0.085
Required δ-r	(rad)	0.402
Required δ-r	(deg)	23.051

Lift and Pitching Moment Calculations:

Airplane X-ac	(cruise)	0.369
Airplane X-ac	(approach)	0.376
Airplane C-L-α	(cruise)	5.579
Airplane C-L-α	(approach)	5.670
Airplane C-M-α	(cruise)	
	Forward C.G.	-1.061
	Aft C.G.	-0.626
Airplane C-M-α	(approach)	
	Forward C.G.	-1.116
	Aft C.G.	-0.673
C-L-i-H	(cruise)	0.778
C-L-i-H	(approach)	0.803

C-L-δ-e	(cruise)	0.420	
C-L-δ-e	(approach)	0.434	
C-M-i-h	(cruise)		bar values
	Forward C.G.	-3.091	-2.942
	Aft C.G.	-3.030	-2.942
C-M-i-h	(approach)		
	Forward C.G.	-3.188	-3.030
	Aft C.G.	-3.126	-3.030
C-M-δ-e	(cruise)		
	Forward C.G.	-1.669	-1.589
	Aft C.G.	-1.636	-1.589
C-M-δ-e	(approach)		
	Forward C.G.	-1.722	-1.636
	Aft C.G.	-1.688	-1.636
Δf C-m-ac	(cruise)	-0.038	
	(approach)	-0.038	
C-m-ac-wb	(cruise)	-0.092	
	(approach)	-0.083	
C-m-o (a-ht)	(cruise)		
	Forward C.G.	-0.047	-0.014
	Aft C.G.	-0.033	-0.014
C-m-o (a-ht)	(approach)		
	Forward C.G.	-0.037	-0.004
	Aft C.G.	-0.024	-0.004
C-y-δ-r	(cruise)	-0.302	
	(approach)	-0.324	
C-n-δ-r	(cruise)	0.074	
	(approach)	0.085	

Lift Curve Equations:	Condition	C-l-o	α	i-h	δ-e	δ-flaps
	Cruise	0.170	0.097	0.014	0.007	0.027
	Min Control	0.170	0.099	0.014	0.008	0.072

Pitching Moment Eqns:	Condition	C-m-o	C-L	i-h	δ-e	C-m-δ-f	Thrust
	Cruise-fwd	-0.014	-0.190	-0.051	-0.028		-0.003
	Cruise-aft	-0.014	-0.112	-0.051	-0.028		-0.003
	Min Cntrl-fw	-0.004	-0.197	-0.053	-0.029	-0.390	-0.113
	Min Cntrl-af	-0.004	-0.119	-0.053	-0.029	-0.390	-0.113
ΔC-m-o H.T.	Forward C.G.	0.137					
	Aft C.G.	0.134					

Take-off Rotation Calculations:

Take-off Thrust T	13,325	
Thrust Moment Arm z-t	1.92	
Drag at T-O D	2,000.00	
Drag Moment Arm z-d	2.00	
Lift at T-O	5,000	
Take-off Weight W-to	28,506	
X-mg	5.00	
X-cg	1.33	
Z-mg	7.75	
X-ac-wb	1.19	
X-ac-h	30.92	
Wheel-ground friction μ	0.02	
q-bar T.O.R.	50.00	
C-l-o-h	0.17	
C-m-ac-wb	-0.08	
H.T. incidence for rotat.	0.18	rad
	10.21	deg
Elevator Deflection	18.90	deg

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36 Passenger Airplane: Calculations for Cruise and M.C. at Fwd and Aft C.G.

Note: All Results in RADIANS

Fwd - Aft

Cruise Mach Number	0.700			
Section Lift Curve Slope	6.000	Forward C.G.	0.267	
Wing-Body ac shift	-0.090	Aft C.G.	0.385	
X-bar C.G.	0.385			
Min Control Dynamic Pres.	51.170	MC A.C.	0.454	
Cruise Dynamic Pressure	215.600	Cruise A.C.	0.454	
Minimum Control Speed	207.500			
Cruise Speed fps	696.290	Static Margin	-0.069	-0.187
1/rad to 1/deg conversion	0.017			

Moments of Inertia:	Forward	Aft
I-xx	70,773	124,022
I-yy	235,569	209,114
I-zz	284,424	310,361
Weights	30,334	28,574

Fuselage:	
Fuselage Height	8.050
Fuselage Width	8.050
Fuselage Length	79.000
C-n-B-body	-0.138

Wing:	
Wing Area sqft	592.000
Wing Span ft	84.300
Wing MGC ft	7.450
Aspect Ratio	12.000
Leading Edge Sweep rad	0.262
Semichord Sweep rad	0.194
C-L-o	0.170
C-m-o-wing (cruise)	-0.054
C-m-o-wing (approach)	-0.045

Wing Lift Curves:

K:1.0544	C-L-a (cruise)	4.7089
k:0.6820	C-L-a (app)	4.7794
B:0.7141		

Horizontal Tail:	
Total H.T. Area sqft	120.000
H.T. Area (each) sqft	120.000
H.T. Span ft	26.569
H.T. Root Chord	6.022
H.T. MGC ft	4.684
H.T. Aspect Ratio	5.883
H.T. LE Sweep rad	0.436
H.T. c/2 Sweep rad	0.314
H.T. Taper Ratio	0.500
X-bar ac-h	4.676
1 - downwash	0.746
H.T. q-bar corr. (eta-h)	1.000
Elevator effectiveness τe	0.540

Horizontal Tail Lift Curves:

K:1.0630	C-L-a (cruise)	3.8395
k:0.6820	C-L-a (app)	3.9610
B:0.71		

Vertical Tail:	
Total V.T. Area sqft	170.000
V.T. Area (each) sqft	170.000
V.T. Span ft	15.400
V.T. MGC ft	12.000
V.T. Aspect Ratio	1.40
V.T. Effective Asp. Ratio	1.960

Vertical Tail Lift Curves:

K:1.0366	C-L-a (cruise)	2.0802
k:0.68	C-L-a (app)	2.2314
B:0.71		

V.T. LE Sweep rad	0.785
V.T. c/2 Sweep rad	0.687
V.T. Taper Ratio	0.330
V.T. Moment Arm l-v	24.506
Approach Alpha e (rad)	0.1745
Approach l-v	25.94
1+(de/dB)	1.477

Engine Mounting Bar:	
Bar Area sqft	112.000
Bar Span ft	11.000
Bar MGC ft	10.200
Bar Aspect Ratio	1.080
Bar LE Sweep rad	0.436
Bar c/2 Sweep rad	0.281
Bar Taper Ratio	0.880
X-bar ac-h	0.828
1 - downwash	1.000
Bar q-bar corr. (eta-h)	1.000

Engine Bar Lift Curves:

K:1.0202	C-L-a (cruise)	1.5317
k:0.68	C-L-a (app)	1.5395
B:0.71		

Total Take-off Thrust lbs	15,481
Total Cruise Thrust (lbs)	1,967
Z-T (vertical mom. arm)	1.920
Y-T (horizontal mom. arm)	10.500

Non-dim. Derivatives:	Cruise-fwd	Cruise-aft	Min Cntrl-fwd	Min Cntrl-aft
C-L-a Airplane	5.579	5.579	5.670	5.670
C-m-a Airplane	-1.041	-0.383	-1.098	-0.429
C-L-a-dot	1.743	1.696	1.798	1.750
C-m-a-dot	-7.686	-7.280	-7.929	-7.510
C-m-q	-33.485	-31.651	-34.539	-32.650
C-y-B	-1.168	-1.168	-1.232	-1.232
C-n-B	0.118	0.118	0.153	0.153
C-y-r	0.513	0.513	0.582	0.582
C-n-r	-0.149	-0.149	-0.179	-0.179

Dimensional Derivatives:	Cruise-fwd	Cruise-aft	Min Cntrl-fwd	Min Cntrl-aft
Z-a:	-755.210	-801.727	-182.143	-193.362
Z-a-dot:	-1.262	-1.304	-1.037	-1.072
M-a:	-4.203	-1.741	-1.052	-0.463
M-a-dot:	-0.166	-0.177	-0.136	-0.146
M-q:	-0.723	-0.770	-0.594	-0.633

Y-β:	-158.093	-167.831	-39.583	-42.021
Y-r:	4.203	4.462	3.801	4.035
N-β:	4.482	4.107	1.376	1.261
N-r:	-0.341	-0.313	-0.327	-0.300
Short Period:				
Frequency	2.233	1.621	1.254	1.026
Damping Ratio	0.442	0.647	0.641	0.833
N-a	23.476	24.922	5.572	5.915
Dutch Roll:				
Frequency	2.129	2.039	1.189	1.139
Damping Ratio	0.134	0.136	0.218	0.220
Omega * Zeta	0.284	0.277	0.259	0.251

Verify Class I Handling Qualities:

Short Period:				
Below max freq.	yes	yes	yes	yes
Above min freq.	yes	yes	yes	yes
Damping	yes	yes	yes	yes
Dutch Roll:				
Frequency	yes	yes	yes	yes
Damping Ratio	yes	yes	yes	yes
Omega * Zeta	yes	yes	yes	yes

Engine-Out Calculations:

C-y-δ-r	-0.324
C-n-δ-r	0.100
Required δ-r (rad)	0.399
Required δ-r (deg)	22.888

Lift and Pitching Moment Calculations:

Airplane X-ac (cruise)	0.454
Airplane X-ac (approach)	0.461
Airplane C-L-a (cruise)	5.579
Airplane C-L-a (approach)	5.670
Airplane C-M-a (cruise)	
Forward C.G.	-1.041
Aft C.G.	-0.383
Airplane C-M-a (approach)	
Forward C.G.	-1.098
Aft C.G.	-0.429
C-L-i-H (cruise)	0.778
C-L-i-H (approach)	0.803

C-L-δ-e	(cruise)	0.420	
C-L-δ-e	(approach)	0.434	
C-M-i-h	(cruise)		bar values
	Forward C.G.	-3.431	-3.286
	Aft C.G.	-3.340	-3.286
C-M-i-h	(approach)		
	Forward C.G.	-3.540	-3.385
	Aft C.G.	-3.445	-3.385
C-M-δ-e	(cruise)		
	Forward C.G.	-1.853	-1.775
	Aft C.G.	-1.803	-1.775
C-M-δ-e	(approach)		
	Forward C.G.	-1.912	-1.828
	Aft C.G.	-1.860	-1.828
Δf C-m-ac	(cruise)	-0.044	
	(approach)	-0.043	
C-m-ac-wb	(cruise)	-0.098	
	(approach)	-0.088	
C-m-o (a-ht)	(cruise)		
	Forward C.G.	-0.037	-0.006
	Aft C.G.	-0.017	-0.006
C-m-o (a-ht)	(approach)		
	Forward C.G.	-0.028	0.005
	Aft C.G.	-0.008	0.005
C-y-δ-r	(cruise)	-0.302	
	(approach)	-0.324	
C-n-δ-r	(cruise)	0.088	
	(approach)	0.100	

Lift Curve Equations:	Condition	C-l-o	α	i-h	δ-e	δ-flaps
	Cruise	0.170	0.097	0.014	0.007	0.027
	Approach	0.170	0.099	0.014	0.008	0.027

Pitching Moment Eqns:	Condition	C-m-o	C-L	i-h	δ-e	C-m-δ-f	Thrust:
	Cruise-fwd	-0.006	-0.187	-0.057	-0.031		-0.004
	Cruise-aft	-0.006	-0.069	-0.057	-0.031		-0.004
	Approach-fwd	0.005	-0.194	-0.059	-0.032	-0.390	-0.132
	Approach-aft	0.005	-0.076	-0.059	-0.032	-0.390	-0.132
ΔC-m-o H.T.	Forward C.G.	0.152					
	Aft C.G.	0.148					

Take-off Rotation Calculations:

Take-off Thrust T	15,481.40	
Thrust Moment Arm z-t	1.92	
Drag at T-O D	2,000.00	
Drag Moment Arm z-d	2.00	
Lift at T-O	5,000.00	
Take-off Weight	30,334.00	
X-mg	5.00	
X-cg	1.99	
Z-mg	7.70	
X-ac-wb	1.19	
X-ac-h	34.84	
Wheel-ground friction	0.02	
q-bar T.O.R.	50.00	
C-l-o-h	0.17	
C-m-ac-wb	-0.09	
H.T. incidence for rotat.	*0.14*	*rad*
	7.95	deg
Elevator Deflection	14.71	deg

36 Passenger Airplane: Calculations for Cruise and M.C. at Fwd and Aft C.G. W_{TO} – W_{OE}

Note: All Results in RADIANS

Cruise Mach Number	0.700			
Section Lift Curve Slope	6.000	Fwd - W-to C.G.	0.280	
Wing-Body ac shift	-0.090	Aft - W-to C.G.	0.385	
X-bar C.G.	0.385			
Min Control Dynamic Pres.	51.170	MC A.C.	0.454	
Cruise Dynamic Pressure	215.600	Cruise A.C.	0.454	
Minimum Control Speed	207.500			
Cruise Speed fps	696.290	Static Margin	-0.069	-0.174
1/rad to 1/deg conversion	0.017			

Moments of Inertia:	Forward	Aft
I-xx	125,220	69,710
I-yy	237,382	207,940
I-zz	339,291	255,999
Weights	35,954	22,954

Fuselage:	
Fuselage Height	8.050
Fuselage Width	8.050
Fuselage Length	79.000
C-n-β-body	-0.138

Wing:	
Wing Area sqft	592.000
Wing Span ft	84.300
Wing MGC ft	7.450
Aspect Ratio	12.000
Leading Edge Sweep rad	0.262
Semichord Sweep rad	0.194
C-L-o	0.170
C-m-o-wing (cruise)	-0.054
C-m-o-wing (approach)	-0.045

Wing Lift Curves:		
K:1.0544	C-L-α (cruise)	4.7089
k:0.6820	C-L-α (app)	4.7794
B:0.7141		

Horizontal Tail:	
Total H.T. Area sqft	120.000
H.T. Area (each) sqft	120.000
H.T. Span ft	26.569
H.T. Root Chord	6.022
H.T. MGC ft	4.684
H.T. Aspect Ratio	5.883
H.T. LE Sweep rad	0.436
H.T. c/2 Sweep rad	0.314
H.T. Taper Ratio	0.500
X-bar ac-h	4.676
1 - downwash	0.746
H.T. q-bar corr. (eta-h)	1.000
Elevator effectiveness τe	0.540

Horizontal Tail Lift Curves:		
K:1.0630	C-L-α (cruise)	3.8395
k:0.6820	C-L-α (app)	3.9610
B:0.71		

Vertical Tail:	
Total V.T. Area sqft	170.000
V.T. Area (each) sqft	170.000
V.T. Span ft	15.400
V.T. MGC ft	12.000
V.T. Aspect Ratio	1.40
V.T. Effective Asp. Ratio	1.960

Vertical Tail Lift Curves:		
K:1.0366	C-L-α (cruise)	2.0802
k:0.68	C-L-α (app)	2.2314
B:0.71		

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V.T. LE Sweep rad	0.785
V.T. c/2 Sweep rad	0.687
V.T. Taper Ratio	0.330
V.T. Moment Arm l-v	24.506
Approach Alpha α (rad)	0.1745
Approach l-v	25.94
1+(dσ/dβ)	1.477

Engine Mounting Bar:

Bar Area sqft	112.000
Bar Span ft	11.000
Bar MGC ft	10.200
Bar Aspect Ratio	1.080
Bar LE Sweep rad	0.436
Bar c/2 Sweep rad	0.281
Bar Taper Ratio	0.880
X-bar ac-h	0.828
1 - downwash	1.000
Bar q-bar corr. (eta-h)	1.000

Engine Bar Lift Curves:

K:1.0202	C-L-α (cruise)	1.5317
k:0.68	C-L-α (app)	1.5395
β:0.71		

Total Take-off Thrust lbs	15,481
Total Cruise Thrust (lbs)	1,967
Z-T (vertical mom. arm)	1.920
Y-T (horizontal mom. arm)	10.500

Non-dim. Derivatives:	Cruise-fwd	Cruise-aft	Min Cntrl-fwd	Min Cntrl-aft
C-L-α Airplane	5.579	5.579	5.670	5.670
C-m-α Airplane	-0.969	-0.383	-1.024	-0.429
C-L-α-dot	1.738	1.696	1.793	1.750
C-m-α-dot	-7.640	-7.280	-7.882	-7.510
C-m-q	-33.279	-31.651	-34.328	-32.650
C-y-β	-1.168	-1.168	-1.232	-1.232
C-n-β	0.118	0.118	0.153	0.153
C-y-r	0.513	0.513	0.582	0.582
C-n-r	-0.149	-0.149	-0.179	-0.179

Dimensional Derivatives:	Cruise-fwd	Cruise-aft	Min Cntrl-fwd	Min Cntrl-aft
Z-α:	-637.162	-998.019	-153.672	-240.704
Z-α-dot:	-1.062	-1.624	-0.872	-1.334
M-α:	-3.881	-1.751	-0.974	-0.466
M-α-dot:	-0.164	-0.178	-0.135	-0.146
M-q:	-0.713	-0.774	-0.586	-0.636

Y-β:	-133.381	-208.922	-33.396	-52.309
Y-r:	3.546	5.555	3.207	5.023
N-β:	3.757	4.980	1.153	1.528
N-r:	-0.286	-0.379	-0.274	-0.363
Short Period:				
Frequency	2.129	1.691	1.186	1.097
Damping Ratio	0.421	0.705	0.616	0.885
N-α	19.806	31.023	4.701	7.363
Dutch Roll:				
Frequency	1.948	2.248	1.086	1.258
Damping Ratio	0.123	0.151	0.200	0.245
Omega * Zeta	0.239	0.340	0.217	0.308

Verify Class I Handling Qualities:

Short Period:				
Below max freq.	yes	yes	yes	yes
Above min freq.	yes	yes	yes	yes
Damping	yes	yes	yes	yes
Dutch Roll:				
Frequency	yes	yes	yes	yes
Damping Ratio	yes	yes	yes	yes
Omega * Zeta	yes	yes	yes	yes

Engine-Out Calculations:

C-y-δ-r	-0.324
C-n-δ-r	0.100
Required δ-r (rad)	0.399
Required δ-r (deg)	22.888

Lift and Pitching Moment Calculations:

Airplane X-ac (cruise)	0.454
Airplane X-ac (approach)	0.461
Airplane C-L-α (cruise)	5.579
Airplane C-L-α (approach)	5.670
Airplane C-M-α (cruise)	
Forward C.G.	-0.969
Aft C.G.	-0.383
Airplane C-M-α (approach)	
Forward C.G.	-1.024
Aft C.G.	-0.429
C-L-i-H (cruise)	0.778
C-L-i-H (approach)	0.803

C-L-δ-e	(cruise)	0.420	
C-L-δ-e	(approach)	0.434	
C-M-i-h	(cruise)		bar values
	Forward C.G.	-3.421	-3.286
	Aft C.G.	-3.340	-3.286
C-M-i-h	(approach)		
	Forward C.G.	-3.530	-3.385
	Aft C.G.	-3.445	-3.385
C-M-δ-e	(cruise)		
	Forward C.G.	-1.847	-1.775
	Aft C.G.	-1.803	-1.775
C-M-δ-e	(approach)		
	Forward C.G.	-1.906	-1.828
	Aft C.G.	-1.860	-1.828
Δf C-m-ac	(cruise)	-0.044	
	(approach)	-0.043	
C-m-ac-wb	(cruise)	-0.098	
	(approach)	-0.088	
C-m-o (a-ht)	(cruise)		
	Forward C.G.	-0.035	-0.006
	Aft C.G.	-0.017	-0.006
C-m-o (a-ht)	(approach)		
	Forward C.G.	-0.026	0.005
	Aft C.G.	-0.008	0.005
C-y-δ-r	(cruise)	-0.302	
	(approach)	-0.324	
C-n-δ-r	(cruise)	0.088	
	(approach)	0.100	

Lift Curve Equations:	Condition	C-l-o	α	i-h	δ-e	δ-flaps
	Cruise	0.170	0.097	0.014	0.007	0.027
	Approach	0.170	0.099	0.014	0.008	0.027

Pitching Moment Eqns:	Condition	C-m-o	C-L	i-h	δ-e	C-m-δ-f	Thrust
	Cruise-fwd	-0.006	-0.174	-0.057	-0.031		-0.004
	Cruise-aft	-0.006	-0.069	-0.057	-0.031		-0.004
	Approach-fwd	0.005	-0.181	-0.059	-0.032	-0.390	-0.132
	Approach-aft	0.005	-0.076	-0.059	-0.032	-0.390	-0.132

ΔC-m-o H.T.	Forward C.G.	0.151
	Aft C.G.	0.148

Take-off Rotation Calculations:

Take-off Thrust T	15,481.40	
Thrust Moment Arm z-t	1.92	
Drag at T-O D	2,000.00	
Drag Moment Arm z-d	2.00	
Lift at T-O	5,000.00	
Take-off Weight	35,954.00	
X-mg	5.00	
X-cg	2.09	
Z-mg	7.70	
X-ac-wb	1.19	
X-ac-h	34.84	
Wheel-ground friction	0.02	
q-bar T.O.R.	50.00	
C-l-o-h	0.17	
C-m-ac-wb	-0.09	
H.T. incidence for rotat.	0.16	rad
	9.10	deg
Elevator Deflection	16.84	deg

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50 Passenger Airplane Calculations for Cruise and M.C. at Fwd and Aft C.G.

Cruise Mach Number	0.700			
Section Lift Curve Slope	6.000	Forward C.G.	0.530	
Wing-Body ac shift	-0.090	Aft C.G.	0.603	
X-bar C.G.	0.603			
Min Cntrl Dynamic Pres.	51.170	approach a.c.	0.673	
Cruise Dynamic Pressure	215.600	cruise a.c.	0.664	
Min Cntrl Speed fps	207.500			
Cruise Speed fps	696.290	static margin	-0.061	-0.134
1/rad to 1/deg conversion	0.017			

Moments of Inertia:	Forward	Aft
I-xx	141,865	73,363
I-yy	465,510	408,670
I-zz	580,046	457,113
Weights	43,141	25,978

Fuselage:

Fuselage Height	8.050
Fuselage Width	8.050
Fuselage Length	96.330
C-n-B-body	-0.141

Wing:

Wing Area sqft	592.000
Wing Span ft	84.300
Wing MGC ft	7.450
Aspect Ratio	12.000
Leading Edge Sweep rad	0.262
Semichord Sweep rad	0.194
C-L-o	0.170
C-m-o-wing (cruise)	-0.054
C-m-o-wing (approach)	-0.045

Wing Lift Curves:

K:1.0544	C-L-a (cruise)	4.7089
k:0.6820	C-L-a (app)	4.7794
B:0.7141		

Horizontal Tail:

Total H.T. Area sqft	120.000
H.T. Area (each) sqft	120.000
H.T. Span ft	26.569
H.T. Root Chord	6.022
H.T. MGC ft	4.684
H.T. Aspect Ratio	5.883
H.T. LE Sweep rad	0.436
H.T. c/2 Sweep rad	0.314
H.T. Taper Ratio	0.500
X-bar ac-h	6.040
1 - downwash	0.746
H.T. q-bar corr. (eta-h)	1.000
Elevator effectiveness τe	0.540

Horizontal Tail Lift Curves:

K:1.0629	C-L-a (cruise)	3.8395
k:0.6820	C-L-a (app)	3.9610
B:0.71		

Vertical Tail:

Total V.T. Area sqft	170.000
V.T. Area (each) sqft	170.000
V.T. Span ft	15.400
V.T. MGC ft	12.000
V.T. Aspect Ratio	1.40
V.T. Effective Asp. Ratio	1.960

Vertical Tail Lift Curves:

K:1.0366	C-L-a (cruise)	2.0802
k:0.68	C-L-a (app)	2.2314
B:0.71		

V.T. LE Sweep rad	0.785
V.T. c/2 Sweep rad	0.687
V.T. Taper Ratio	0.330
V.T. Moment Arm l-v	32.342
Approach Alpha a (rad)	0.1745
Approach l-v	33.66
1+(dσ/dβ)	1.477

Engine Mounting Bar:	
Bar Area sqft	112.000
Bar Span ft	11.000
Bar MGC ft	10.200
Bar Aspect Ratio	1.080
Bar LE Sweep rad	0.436
Bar c/2 Sweep rad	0.281
Bar Taper Ratio	0.880
X-bar ac-h	2.148
1 - downwash	1.000
Bar q-bar corr. (eta-h)	1.000

Engine Bar Lift Curves:

K:1.0202	C-L-a (cruise)		1.5320
k:0.68	C-L-a (app)		1.5399
β:0.71			

Total Take-off Thrust lbs	18,929
Total Cruise Thrust (lbs)	4,047
Z-T (vertical mom. arm)	1.920
Y-T (horizontal mom. arm)	10.000

	Cruise-fwd	Cruise-aft	Min Cntrl-fwd	Min Cntrl-aft
C-L-a Airplane	5.579	5.579	5.670	5.670
C-m-a Airplane	-0.749	-0.341	-0.808	-0.395
C-L-a-dot	2.178	2.150	2.247	2.218
C-m-a-dot	-12.003	-11.687	-12.383	-12.057
C-m-q	-53.652	-52.137	-55.306	-53.747
C-y-β	-1.168	-1.168	-1.232	-1.232
C-n-β	0.197	0.197	0.237	0.237
C-y-r	0.677	0.677	0.756	0.756
C-n-r	-0.260	-0.260	-0.302	-0.302

	Cruise-fwd	Cruise-aft	Min Cntrl-fwd	Min Cntrl-aft
Z-a:	-531.022	-881.855	-128.073	-212.688
Z-a-dot:	-1.109	-1.818	-0.911	-1.493
M-a:	-1.529	-0.794	-0.392	-0.218
M-a-dot:	-0.131	-0.145	-0.108	-0.120
M-q:	-0.586	-0.649	-0.481	-0.533

Y-β:	-111.161	-184.602	-27.832	-46.220
Y-r:	3.900	6.477	3.468	5.759
N-β:	3.663	4.649	1.043	1.323
N-r:	-0.292	-0.370	-0.270	-0.342
Short Period:				
Frequency	1.406	1.271	0.830	0.874
Damping Ratio	0.526	0.811	0.727	0.959
N-α	16.507	27.412	3.918	6.506
Dutch Roll:				
Frequency	1.921	2.169	1.030	1.167
Damping Ratio	0.117	0.146	0.196	0.242
Omega * Zeta	0.226	0.318	0.202	0.283

Verify Class I Handling Qualities:

Short Period:				
Below max freq.	yes	yes	yes	yes
Above min freq.	yes	no	yes	no
Damping	yes	yes	yes	yes
Dutch Roll:				
Frequency	yes	yes	yes	yes
Damping Ratio	yes	yes	yes	yes
Omega * Zeta	yes	yes	yes	yes

Engine-Out Calculations:

C-y-δ-r	-0.324
C-n-δ-r	0.129
Required δ-r (rad)	0.359
Required δ-r (deg)	20.542

Lift and Pitching Moment Calculations:

Airplane X-ac (cruise)	0.664
Airplane X-ac (approach)	0.673
Airplane C-L-α (cruise)	5.579
Airplane C-L-α (approach)	5.670
Airplane C-M-α (cruise)	
Forward C.G.	-0.749
Aft C.G.	-0.341
Airplane C-M-α (approach)	
Forward C.G.	-0.808
Aft C.G.	-0.395
C-L-i-H (cruise)	0.778
C-L-i-H (approach)	0.803

C-L-δ-e	(cruise)	0.420	
C-L-δ-e	(approach)	0.434	
C-M-i-h	(cruise)		bar values
	Forward C.G.	-4.288	-4.184
	Aft C.G.	-4.231	-4.184
C-M-i-h	(approach)		
	Forward C.G.	-4.424	-4.310
	Aft C.G.	-4.365	-4.310
C-M-δ-e	(cruise)		
	Forward C.G.	-2.316	-2.259
	Aft C.G.	-2.285	-2.259
C-M-δ-e	(approach)		
	Forward C.G.	-2.389	-2.327
	Aft C.G.	-2.357	-2.327
Δf C-m-ac	(cruise)	-0.057	
	(approach)	-0.056	
C-m-ac-wb	(cruise)	-0.111	
	(approach)	-0.101	
C-m-o (a-ht)	(cruise)		
	Forward C.G.	-0.006	0.017
	Aft C.G.	0.007	0.017
C-m-o (a-ht)	(approach)		
	Forward C.G.	0.004	0.028
	Aft C.G.	0.017	0.028
C-y-δ-r	(cruise)	-0.302	
	(approach)	-0.324	
C-n-δ-r	(cruise)	0.116	
	(approach)	0.129	

Lift Curve Equations:	Condition	C-l-o	α	i-h	δ-e	δ-flaps
	Cruise	0.170	0.097	0.014	0.007	0.027
	Approach	0.170	0.099	0.014	0.008	0.027

Pitching Moment Eqns:	Condition	C-m-o	C-L	i-h	δ-e	C-m-δ-flaps	Thrust
	Cruise-fwd	0.017	-0.134	-0.073	-0.039		-0.008
	Cruise-aft	0.017	-0.061	-0.073	-0.039		-0.008
	Approach-fwd	0.028	-0.143	-0.075	-0.041	-0.390	-0.161
	Approach-aft	0.028	-0.070	-0.075	-0.041	-0.390	-0.161

ΔC-m-o H.T.	Forward C.G.	0.190
	Aft C.G.	0.187

Take-off Rotation Calculations:

Take-off Thrust T	18,928.80	
Thrust Moment Arm z-t	1.92	
Drag at T-O D	2,000.00	
Drag Moment Arm z-d	2.00	
Lift at T-O	5,000.00	
Take-off Weight	43,141.00	
X-mg	5.00	
X-cg	3.92	
Z-mg	7.67	
X-ac-wb	1.19	
X-ac-h	45.00	
Wheel-ground friction μ	0.02	
q-bar T.O.R.	50.00	
C-l-o-h	0.17	
C-m-ac-wb	-0.10	
H.T. incidence for rotat.	0.06	rad
	3.32	deg
Elevator Deflection	6.15	deg

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75 Passenger Twin-body:

Note: All Results in RADIANS

Cruise Mach Number	0.700
Section Lift Curve Slope	6.000
Wing-Body ac shift	-0.140
X-bar C.G.	0.769
Min Cntrl Dynamic Pres.	51.170
Cruise Dynamic Pressure	215.600
Min Cntrl Speed fps	207.500
Cruise Speed fps	696.290
1/rad to 1/deg conversion	0.017

Forward C.G.	0.602	
Aft C.G.	0.769	
Cruise A.C.	0.821	
Approach A.C.	0.813	
Static Margin	-0.052	-0.219

Moments of Inertia:	Forward	Aft
I-xx	1,355,496	761,328
I-yy	505,928	441,252
I-zz	1,779,110	1,125,135
Weights	71,419	44,804

Fuselage:	
Fuselage Height	8.050
Fuselage Width	16.100
Fuselage Length	79.000
C-n-B-body	-0.121

Wing:	
Wing Area sqft	1,182.000
Wing Span ft	132.500
Wing MGC ft	8.970
Aspect Ratio	14.853
Leading Edge Sweep rad	0.201
Semichord Sweep rad	0.169
C-L-o	0.170
C-m-o-wing (cruise)	-0.059
C-m-o-wing (approach)	-0.049

Wing Lift Curves:		
K:1.0493	C-L-a (cruise)	4.9102
k:0.6820	C-L-a (app)	4.9678
B:0.7141		

Horizontal Tail:	
Total H.T. Area sqft	410.000
H.T. Area (each) sqft	410.000
H.T. Span ft	74.770
H.T. MGC ft	5.629
H.T. Aspect Ratio	13.600
H.T. LE Sweep rad	0.070
H.T. c/2 Sweep rad	0.052
H.T. Taper Ratio	0.500
X-bar ac-h	4.283
1 - downwash	0.786
H.T. q-bar corr. (eta-h)	1.000
Elevator effectiveness τe	0.540

Horizontal Tail Lift Curves:		
K:1.0519	C-L-a (cruise)	4.9475
k:0.6820	C-L-a (app)	4.9530
B:0.71		

Vertical Tail:	
Total V.T. Area sqft	340.000
V.T. Area (each) sqft	170.000
V.T. Span ft	15.400
V.T. MGC ft	12.000
V.T. Aspect Ratio	1.40
V.T. Effective Asp. Ratio	1.960
V.T. LE Sweep rad	0.785

Vertical Tail Lift Curves:		
K:1.0366	C-L-a (cruise)	2.0802
k:0.68	C-L-a (app)	2.2314
B:0.71		

V.T. c/2 Sweep rad	0.687
V.T. Taper Ratio	0.330
V.T. Moment Arm l-v	23.185
Approach Alpha α (rad)	0.1745
Approach l-v	24.64
1+(dα/dβ)	1.477

Engine Mounting Bar:

Bar Area sqft	165.800
Bar Span ft	15.700
Bar MGC ft	10.620
Bar Aspect Ratio	1.487
Bar LE Sweep rad	0.436
Bar c/2 Sweep rad	0.314
Bar Taper Ratio	0.814
X-bar ac-h	0.994
1 - downwash	1.000
Bar q-bar corr. (eta-h)	1.000

Engine Bar Lift Curves:

K:1.0278	C-L-α (cruise)	1.9622
k:0.68	C-L-α (app)	1.9824
β:0.71		

Total Take-off Thrust lbs	37,891
Total Cruise Thrust (lbs)	3,747
Z-T (vertical mom. arm)	5.170
Y-T (horizontal mom. arm)	10.000

Non-dim. Derivatives:	Cruise-fwd	Cruise-aft	Min Cntrl-fwd	Min Cntrl-aft
C-L-α Airplane	6.534	6.534	6.596	6.596
C-m-α Airplane	-1.430	-0.339	-1.394	-0.292
C-L-α-dot	2.704	2.581	2.707	2.584
C-m-α-dot	-9.952	-9.070	-9.964	-9.080
C-m-q	-51.250	-46.651	-51.308	-46.704
C-y-β	-1.027	-1.027	-1.091	-1.091
C-n-β	0.034	0.034	0.055	0.055
C-y-r	0.309	0.309	0.353	0.353
C-n-r	-0.054	-0.054	-0.066	-0.066

Dimensional Derivatives:	Cruise-fwd	Cruise-aft	Min Cntrl-fwd	Min Cntrl-aft
Z-α:	-750.072	-1,195.639	-179.708	-286.461
Z-α-dot:	-1.999	-3.042	-1.594	-2.425
M-α:	-6.460	-1.754	-1.495	-0.359
M-α-dot:	-0.290	-0.303	-0.231	-0.241
M-q:	-1.492	-1.557	-1.189	-1.241

Y-β:	-117.871	-187.890	-29.726	-47.385
Y-r:	3.378	5.385	3.067	4.889
N-β:	0.639	1.010	0.249	0.394
N-r:	-0.098	-0.155	-0.094	-0.149
Short Period:				
Frequency	2.840	2.104	1.589	1.440
Damping Ratio	0.503	0.850	0.719	0.994
N-α	23.316	37.166	5.534	8.821
Dutch Roll:				
Frequency	0.807	1.022	0.509	0.647
Damping Ratio	0.165	0.208	0.233	0.292
Omega * Zeta	0.134	0.212	0.119	0.189

Verify Class I Handling Qualities:

Short Period:				
Below max freq.	yes	yes	yes	yes
Above min freq.	yes	yes	yes	yes
Damping	yes	yes	yes	yes
Dutch Roll:				
Frequency	yes	yes	yes	yes
Damping Ratio	yes	yes	yes	yes
Omega * Zeta	no	yes	no	yes

Engine-Out Calculations:

C-y-δ-r		-0.324
C-n-δ-r		0.060
Required δ-r	(rad)	0.490
Required δ-r	(deg)	28.084

Lift and Pitching Moment Calculations:

Airplane X-ac (cruise)	0.821
Airplane X-ac (approach)	0.813
Airplane C-L-α (cruise)	6.534
Airplane C-L-α (approach)	6.596
Airplane C-M-α (cruise)	
Forward C.G.	-1.430
Aft C.G.	-0.339
Airplane C-M-α (approach)	
Forward C.G.	-1.394
Aft C.G.	-0.292
C-L-i-H (cruise)	1.716
C-L-i-H (approach)	1.718
C-L-δ-e (cruise)	0.927

C-L-δ-e	(approach)	0.928	
C-M-i-h	(cruise)		bar values
	Forward C.G.	-6.317	-5.942
	Aft C.G.	-6.031	-5.942
C-M-i-h	(approach)		
	Forward C.G.	-6.324	-5.961
	Aft C.G.	-6.037	-5.961
C-M-δ-e	(cruise)		
	Forward C.G.	-3.411	-3.208
	Aft C.G.	-3.256	-3.208
C-M-δ-e	(approach)		
	Forward C.G.	-3.415	-3.219
	Aft C.G.	-3.260	-3.219
Δf C-m-ac	(cruise)	-0.023	
	(approach)	-0.023	
C-m-ac-wb	(cruise)	-0.082	
	(approach)	-0.072	
C-m-o (a-ht)	(cruise)		
	Forward C.G.	0.044	0.081
	Aft C.G.	0.072	0.081
C-m-o (a-ht)	(approach)		
	Forward C.G.	0.054	0.090
	Aft C.G.	0.083	0.090
C-y-δ-r	(cruise)	-0.302	
	(approach)	-0.324	
C-n-δ-r	(cruise)	0.053	
	(approach)	0.060	

Lift Curve Equations:	Condition	C-l-o	α	i-h	δ-e	δ-flaps
	Cruise	0.170	0.114	0.030	0.016	0.027
	Approach	0.170	0.115	0.030	0.016	0.027

Pitching Moment Eqns:	Condition	C-m-o	C-L	i-h	δ-e	δ-flaps	Thrust
	Cruise-fwd	0.081	-0.219	-0.104	-0.056		-0.008
	Cruise-aft	0.081	-0.052	-0.104	-0.056		-0.008
	Approach-fwd	0.090	-0.211	-0.104	-0.056	-0.390	-0.361
	Approach-aft	0.090	-0.044	-0.104	-0.056	-0.390	-0.361

ΔC-m-o H.T.	Forward C.G.	0.064
	Aft C.G.	0.061

Take-off Rotation Calculations:

Take-off Thrust T	37,890.60
Thrust Moment Arm z-t	5.17
Drag at T-O D	3,500.00
Drag Moment Arm z-d	2.00
Lift at T-O	10,000.00
Take-off Weight W-to	71,419.00
X-mg	5.00
X-cg	5.40
Z-mg	7.70
X-ac-wb	0.99
X-ac-h	38.42
Wheel-ground friction	0.02
q-bar T.O.R.	50.00
C-l-o-h	0.17
C-m-ac-wb	-0.07
H.T. incidence for rotat.	0.02 rad
	1.09 deg
Elevator Deflection	2.02 deg

5

100 Passenger Twin-body:

Note: All Results in RADIANS

Cruise Mach Number	0.700
Section Lift Curve Slope	6.000
Wing-Body ac shift	-0.140
X-bar C.G.	0.802
Min Cntrl Dynamic Pres.	50.286
Cruise Dynamic Pressure	215.600
Min Cntrl Speed fps	207.500
Cruise Speed fps	696.290
1/rad to 1/deg conversion	0.017

Forward C.G.	0.659	
Aft C.G.	0.802	
Cruise A.C.	0.991	
Min Cntrl A.C.	0.982	
Static Margin	-0.189	-0.332

Moments of Inertia:	Forward	Aft
I-xx	1,646,875	888,448
I-yy	769,820	653,359
I-zz	2,326,135	1,455,491
Weights	85,044	50,666

Fuselage:

Fuselage Height	8.050
Fuselage Width	16.100
Fuselage Length	96.330
C-n-β-body	-0.129

Wing:

Wing Area sqft	1,182.000
Wing Span ft	132.500
Wing MGC ft	8.970
Aspect Ratio	14.843
Leading Edge Sweep rad	0.201
Semichord Sweep rad	0.169
C-L-o	0.170
C-m-o-wing (cruise)	-0.059
C-m-o-wing (approach)	-0.049

Wing Lift Curves:

K:1.0493	C-L-α (cruise)	4.9090
k:0.6820	C-L-α (app)	4.9669
β:0.7141		

Horizontal Tail:

Total H.T. Area sqft	410.000
H.T. Area (each) sqft	410.000
H.T. Span ft	74.770
H.T. MGC ft	5.629
H.T. Aspect Ratio	13.600
H.T. LE Sweep rad	0.070
H.T. c/2 Sweep rad	0.052
H.T. Taper Ratio	0.500
X-bar ac-h	4.942
1 - downwash	0.786
H.T. q-bar corr. (eta-h)	1.000
Elevator effectiveness τe	0.540

Horizontal Tail Lift Curves:

K:1.0519	C-L-α (cruise)	4.9475
k:0.6820	C-L-α (app)	4.9530
β:0.71		

Vertical Tail:

Total V.T. Area sqft	340.000
V.T. Area (each) sqft	170.000
V.T. Span ft	15.400
V.T. MGC ft	12.000
V.T. Aspect Ratio	1.40
V.T. Effective Asp. Ratio	1.960
V.T. LE Sweep rad	0.785

Vertical Tail Lift Curves:

K:1.0366	C-L-α (cruise)	2.0802
k:0.68	C-L-α (app)	2.2314
β:0.71		

V.T. c/2 Sweep rad	0.687
V.T. Taper Ratio	0.330
V.T. Moment Arm l-v	30.060
Approach Alpha a (rad)	0.1745
Approach l-v	31.41
1+(dσ/dβ)	1.477

Engine Mounting Bar:

Bar Area sqft	165.800
Bar Span ft	15.700
Bar MGC ft	10.620
Bar Aspect Ratio	1.487
Bar LE Sweep rad	0.436
Bar c/2 Sweep rad	0.314
Bar Taper Ratio	0.814
X-bar ac-h	1.794
1 - downwash	1.000
Bar q-bar corr. (eta-h)	1.000

Engine Bar Lift Curves:

K:1.0278	C-L-a (cruise)	1.9622
k:0.68	C-L-a (app)	1.9824
β:0.71		

Total Take-off Thrust lbs	37,891
Total Cruise Thrust (lbs)	4,414
Z-T (vertical mom. arm)	5.330
Y-T (horizontal mom. arm)	10.000

Non-dim. Derivatives:	Cruise-fwd	Cruise-aft	Min Cntrl-fwd	Min Cntrl-aft
C-L-a Airplane	6.533	6.533	6.595	6.595
C-m-a Airplane	-2.167	-1.233	-2.131	-1.188
C-L-a-dot	3.146	3.041	3.149	3.044
C-m-a-dot	-13.474	-12.589	-13.489	-12.603
C-m-q	-70.038	-65.306	-70.124	-65.385
C-y-β	-1.027	-1.027	-1.091	-1.091
C-n-β	0.071	0.071	0.096	0.096
C-y-r	0.401	0.401	0.449	0.449
C-n-r	-0.091	-0.091	-0.107	-0.107

Dimensional Derivatives:	Cruise-fwd	Cruise-aft	Min Cntrtl-fwd	Min Cntrl-aft
Z-a:	-629.787	-1,057.111	-148.290	-248.908
Z-a-dot:	-1.953	-3.169	-1.531	-2.483
M-a:	-6.436	-4.314	-1.476	-0.969
M-a-dot:	-0.258	-0.284	-0.202	-0.222
M-q:	-1.340	-1.472	-1.050	-1.153

Y-β:	-98.987	-166.151	-24.532	-41.178
Y-r:	3.678	6.174	3.227	5.416
N-β:	1.038	1.659	0.324	0.518
N-r:	-0.126	-0.201	-0.115	-0.184
Short Period:				
Frequency	2.765	2.559	1.492	1.534
Damping Ratio	0.452	0.640	0.659	0.839
N-α	19.577	32.860	4.566	7.664
Dutch Roll:				
Frequency	1.025	1.301	0.577	0.736
Damping Ratio	0.131	0.169	0.202	0.260
Omega * Zeta	0.134	0.220	0.117	0.191

Verify Class I Handling Qualities:

Short Period:				
Below max freq.	yes	yes	yes	yes
Above min freq.	yes	yes	yes	yes
Damping	yes	yes	yes	yes
Dutch Roll:				
Frequency	yes	yes	yes	yes
Damping Ratio	yes	yes	yes	yes
Omega * Zeta	no	yes	no	yes

Engine-Out Calculations:

C-y-δ-r		-0.324
C-n-δ-r		0.077
Required δ-r	(rad)	0.391
Required δ-r	(deg)	22.418

Lift and Pitching Moment Calculations:

Airplane X-ac (cruise)	0.991
Airplane X-ac (approach)	0.982
Airplane C-L-α (cruise)	6.533
Airplane C-L-α (approach)	6.595
Airplane C-M-α (cruise)	
Forward C.G.	-2.167
Aft C.G.	-1.233
Airplane C-M-α (approach)	
Forward C.G.	-2.131
Aft C.G.	-1.188
C-L-i-H (cruise)	1.716
C-L-i-H (approach)	1.718
C-L-δ-e (cruise)	0.927

C-L-δ-e	(approach)	0.928	
C-M-i-h	(cruise)		bar values
	Forward C.G.	-7.350	-6.781
	Aft C.G.	-7.105	-6.781
C-M-i-h	(approach)		
	Forward C.G.	-7.358	-6.803
	Aft C.G.	-7.113	-6.803
C-M-δ-e	(cruise)		
	Forward C.G.	-3.969	-3.662
	Aft C.G.	-3.837	-3.662
C-M-δ-e	(approach)		
	Forward C.G.	-3.974	-3.674
	Aft C.G.	-3.841	-3.674
Δf C-m-ac	(cruise)	-0.034	
	(approach)	-0.033	
C-m-ac-wb	(cruise)	-0.093	
	(approach)	-0.082	
C-m-o (a-ht)	(cruise)		
	Forward C.G.	0.043	0.100
	Aft C.G.	0.068	0.100
C-m-o (a-ht)	(approach)		
	Forward C.G.	0.054	0.109
	Aft C.G.	0.078	0.109
C-y-δ-r	(cruise)	-0.302	
	(approach)	-0.324	
C-n-δ-r	(cruise)	0.069	
	(approach)	0.077	

Lift Curve Equations:	Condition	C-l-o	α	i-h	δ-e	δ-flaps
	Cruise	0.170	0.114	0.030	0.016	0.027
	Approach	0.170	0.115	0.030	0.016	0.027

Pitching Moment Eqns:	Condition	C-m-o	C-L	i-h	δ-e	C-m-δ-flaps	Thrust
	Cruise-fwd	0.100	-0.332	-0.118	-0.064		-0.010
	Cruise-aft	0.100	-0.189	-0.118	-0.064		-0.010
	Approach-fwd	0.109	-0.323	-0.119	-0.064	-0.390	-0.379
	Approach-aft	0.109	-0.180	-0.119	-0.064	-0.390	-0.379
ΔC-m-o H.T.	Forward C.G.	0.074					
	Aft C.G.	0.071					

AT AFP

Dynamic Pres. (psf)	51.17				
Speed (fps)	207.5				
	25	36	50	75	100
Wing area	592	592	592	1182	1182
Wing span	84.3	84.3	84.3	132.5	132.5
I-xx-fwd	67265	70773	141865	1355496	1646875
I-xx-aft	102964	124022	73363	761328	888448
C-l-p	-0.5818	-0.5818	-0.5818	-0.6323	-0.6318
C-l-Delta-A	0.455	0.455	0.455	0.443	0.443
L-p-fwd	-4.4867	-4.2643	-2.1274	-1.1936	-0.9816
L-p-aft	-2.9311	-2.4334	-4.1138	-2.1250	-1.8196
T-R-fwd	0.2229	0.2345	0.4701	0.8378	1.0187
T-R-aft	0.3412	0.4109	0.2431	0.4706	0.5496
Handling Level	1	1	1	1	1
L-Delta-A-fwd	17.2738	16.4176	8.1903	2.6191	2.1557
L-Delta-A-aft	11.2847	9.3687	15.8380	4.6632	3.9960
Delta-A (deg)	10	10	10	20	20
Time (sec)	1.9	1.9	1.9	1.9	1.9
Phi-fwd (deg)	64.570	64.124	55.370	50.423	45.638
Phi-aft (deg)	60.065	57.484	63.795	63.098	60.074
Handling Level	1	1	1	1	1

AT APP

Dynamic Pres. (psf)	51.17				
Speed (fps)	207.5				
	25	36	50	75	100
Wing area	592	592	592	1182	1182
Wing span	84.3	84.3	84.3	132.5	132.5
I-xx-fwd	67265	70773	141865	1355496	1646875
I-xx-aft	102964	124022	73363	761328	888448
C-l-p	-0.5818	-0.5818	-0.5818	-0.6323	-0.6318
C-l-Delta-A	0.455	0.455	0.455	0.443	0.443
L-p-fwd	-4.4867	-4.2643	-2.1274	-1.1936	-0.9816
L-p-aft	-2.9311	-2.4334	-4.1138	-2.1250	-1.8196
T-R-fwd	0.2229	0.2345	0.4701	0.8378	1.0187
T-R-aft	0.3412	0.4109	0.2431	0.4706	0.5496
Handling Level	1	1	1	1	1
L-Delta-A-fwd	17.2738	16.4176	8.1903	2.6191	2.1557
L-Delta-A-aft	11.2847	9.3687	15.8380	4.6632	3.9960
Delta-A (deg)	10	10	10	10	10
Time (sec)	1.5	1.5	1.5	1.5	1.5
Phi-fwd (deg)	49.179	48.736	40.397	17.599	15.701
Phi-aft (deg)	44.777	42.340	48.410	23.016	21.660
Handling Level	1	1	1	1	1

APPENDIX E

ARAMID ALUMINUM DATA SUMMARY

Table of Contents

September 4, 1986

Preliminary Overview of Feasibility of using ARALL

as a Primary Component of Aircraft Structures

ARALL - Aramid Aluminum Laminate, based upon an August 1983 report.

E.1 PROPERTIES:

	2024T3	7075T6	ARALL*
.2% Yield Stress (KSI)	52	70	77
Ultimate Tensile Stress (KSI)	68	81	114
Proportional Limit Comp. (KSI)	39	70	47
Youngs Modulus (KSI)	10440	10440	9135
Failure Strain %	17	11	3.5
Specific Weight	2.8	2.8	2.45
Density lb/ft^3	174.8	174.8	152.95

*ARALL 7075-T6 sheets with intermediate modulus fibers and pre-strained.

E.2 STRENGTHS:

High static strength particularly in tensile yield stress.

High fatigue resistance, in fact it is almost fatigue insensitive, with a life cycle of a factore of ten(10) times more testing cycles.

Better corrosion resistance, including the bondline when pretreated.

Delamination under heavy loads and corrosive environment is no problem.

Quality control by C-scan and Fokker bond tester easily detected delamination and voids.

E.3 MACHINABILITY:

Easily cut, drilled, sawn and milled by normal workshop procedures.

Countersinking is possible with conventional rivets. Briles rivets are ideal for thin skin installation.

Adhesive bonding with pretreatment and high temperature curing is allowable.

This material can also be bolted.

Plastic sheet bending is possible, including fabrication of stiffeners and limited double curvature bending.

E.4 AREAS OF CONCERN:

Prestressing of fibers, a technique to obtain better compressive properties, is "rather expensive".

Strength decreases with moisture absorption. Stiffness is not significantly affected.

Notched fracture toughness is comparable or worse than Al alloy. (Intermediate modulus fibers had best properties when notched)

Low fracture toughness when through the thickness damage(cut fibers) occurred. Although it had far superior fracture toughness with the fibers intact. This is offset by whether such accidental damage will ever occur.

Avoid peel forces higher than 0.146 psf.

E.5 MOST LIKELY STRUCTURAL COMPONENT USES:

Where panelloading is above 6.27 psf, probably in lower skin of wing

cylindrical part of pressure cabin

Lower Wing: Changes from fatigue critical to mainly critical in compression(negative gust case).

Fuselage has two critical areas:

Bottom: Fatigue critical in tangential; compression critical in axial.

Crown: Fatigue critical.

Overall, where used yielded about 30 percent decrease in structural weight.

Appendix F

Calculations of stick forces and stick force gradients.

Purpose: This appendix, using the methods of Reference 10:

a) Longitudinal stick forces

b) Rudder pedal forces

c) Aileron wheel force

d) Stick force speed gradient

e) Stick force per G gradient

f) Rudder pedal force per sideslip gradient

g) Control surface hinge moments

REFER TO SPREASHEET:

$$R = \frac{\delta t}{\delta E}$$

$$C_{h_{\delta_E}}(t+E) = C_{h_{\delta_E}} + C_{h_{\delta_t}} R$$

$\alpha_{o_{TRIM}}$ Eqn. 5.134

$\delta_{o_{TRIM}}$ 5.135

$$\frac{\partial \alpha}{\partial C_L} = \frac{C_{m_{\delta_E}}}{C_{L_\alpha} C_{m_{\delta_E}} - C_{m_\alpha} C_{L_{\delta_E}}}$$

$\frac{\partial \delta_E}{\partial C_L}$ Eqn. 5.46

α_{TRIM} Eqn. 5.132

$\delta_{E_{TRIM}}$ 5.133

$$C_h = C_{h_\alpha} \alpha_H + C_{h_\alpha} \alpha_H + C_{h_{\delta_E}} \delta_E \qquad (C_{h_0} = 0)$$

SM_{FREE} Eqn. 5.154

$\frac{\partial F}{\partial n}$ Eqn. 5.163

$\frac{\partial F}{\partial V}$ 5.138

$$F_S = G \cdot HM$$

EQN'S IN REF. [illegible]

25 Pax Stick Force Calculations

	F.C. 1	F.C. 2	F.C. 3	F.C. 4
	Fwd c.g. Cruise	Fwd c.g. Vmc	Aft c.g. Cruise	Aft c.g. Vmc
h (ft)	30000	0	30000	0
density (slugs/ft3)	8.893e-4	2.377e-3	8.893e-4	2.377e-3
V (fps)	696.3	207.5	696.3	207.5
q-bar (psf)	215.58	51.17	215.58	51.17
X-bar-AC	.369	.376	.369	.376
X-bar-cg	.145	.145	.280	.280
Geometries, Inertias				
S (ft2)	592	592	592	592
b (ft)	84.30	84.30	84.30	84.30
c-bar (ft)	7.45	7.45	7.45	7.45
W (lb)	24739	24739	23381	23381
Ixx (slug-ft2)	67265	67265	102964	102964
Iyy (slug-ft2)	130433	130433	122535	122535
Izz (slug-ft2)	177066	177066	180634	180634
Ixz (slug-ft2)	224	224	208	208
Steady State Coefficients				
CL	.194	.817	.183	.772
CD	.014	.145	.014	.143
Longitudinal Derivatives				
C-L-a-A (rad-1)	5.58	5.67	5.58	5.67
C-m-dE (rad-1)	-1.68	-1.74	-1.63	-1.68
C-L-o	.170	.170	.170	.170
C-m-o	-.014	-.004	-.014	-.004
C-L-dE (rad-1)	.420	.434	.420	.434
C-L-i-H (rad-1)	.778	.803	.778	.803
C-m-i-H (rad-1)	-3.117	-3.216	-3.012	-3.107
C-m-alpha (rad-1)	-1.251	-1.308	-.498	-.543
C-m-q (rad-1)	-27.470	-28.340	-25.640	-26.460
	FC 1	FC 2	FC 3	FC 4
Lateral-Directional Derivatives				
C-n-Beta (rad-1)	.045	.078	.045	.078
C-l-p	-.715	-.582	-.715	-.582
C-l-dA (rad-1)	.553	.455	.553	.455
C-n-dR (rad-1)	.085	.079	.085	.079

Longitudinal Stick Force Calculations

>>	Eta-H	1.00	1.00	1.00	1.00
>>	Gearing Ratio (rad/ft)	.72	.72	.72	.72
>>	S-Elev. (ft2)	42.00	42.00	42.00	42.00
>>	C-Elev. (ft)	1.640	1.640	1.640	1.640
>>	C-h-dE (rad-1)	-.469	-.323	-.469	-.323
~~>>~~	~~dE (deg)~~	~~-2.80~~	~~5.75~~	~~-3.60~~	~~-2.00~~
>>	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
~~>>~~	~~d-tab (deg)~~	~~-7.00~~	~~.00~~	~~6.70~~	~~.00~~
>>	S-tab (ft2)	7.000	7.000	7.000	7.000
>>	C-tab (ft)	.570	.570	.570	.570
>>	C-h-alpha (rad-1)	-.263	-.177	-.263	-.177
>>	l-H (ft)	29.84	29.84	28.83	28.83
>>	Tau-E	.540	.540	.540	.540
>>	i-H (rad)	.014	.014	.014	.014
>>	dE/da	.254	.254	.254	.254
>>	n/alpha (g/rad)	28.79	6.83	30.46	7.23
>>	n-Limit	2.50	2.50	2.50	2.50
>>	R (d-tab / d-elev.)	.00	.00	.00	.00
	C-h-dE (tab + elev.)	-.4690	-.3230	-.4690	-.3230
	alpha-o-trim (rad)	-.032	-.032	-.031	-.031
	delta-o-trim (rad)	-.011	-.004	-.025	-.018
	d-alpha/dCL	.190	.187	.183	.181
	d-dE/dCL	-.141	-.141	-.056	-.059
	alpha-trim (rad)	.005	.121	.003	.109
	del-E-trim (rad)	-.038	-.120	-.035	-.064
>>	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	7.86e-5	1.11e-3	2.96e-5	4.353e-4
	d-delE/dn (rad/g)	-.036	-.212	-.018	-.135
	c-h	.0165	.0172	.0158	.0012
	S.M.(FREE)	.098	.106	-.033	-.025
	dF/dn (lbs/g)	69.31	64.66	-6.20	13.63
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	80.00	80.00	80.00
	Passes MIL-F-8785C	yes	yes	no	no
	dF/dV (lbs/knot)	.232	.076	.434	.184
	F-S (lbs)	176.48	43.56	169.27	3.15

	A	B	C	D	E	F	G	H
73	>>	R (d-tab / d-elev.)			1.00	1.00	1.00	1.00
74		C-h-dE (tab + elev.)			-1.4910	-1.3560	-1.4910	-1.3560
75								
76		alpha-o-trim (rad)			-.032	-.032	-.031	-.031
77		delta-o-trim (rad)			-.011	-.004	-.025	-.018
78								
79		d-alpha/dCL			.190	.187	.183	.181
80		d-dE/dCL			-.141	-.141	-.056	-.059
81								
82		alpha-trim (rad)			.005	.121	.003	.109
83		del-E-trim (rad)			-.038	-.120	-.035	-.064
84								
85	>>	Load Factor (g's)			1.00	1.00	1.00	1.00
86		d-delE/dV (rad/fps)			7.86e-5	1.11e-3	2.96e-5	4.353e-4
87		d-delE/dn (rad/g)			-.036	-.212	-.018	-.135
88								
89		c-h			.0554	.1407	.0521	.0669
90								
91		S.M.(FREE)			.184	.201	.051	.067
92								
93		dF/dn (lbs/g)			391.32	457.87	142.11	234.05
94								
95		dF/dn MIN			23.33	23.33	23.33	23.33
96		dF/dn MAX			80.00	80.00	80.00	80.00
97								
98		Passes MIL-F-8785C			no	no	no	no
99								
100		dF/dV (lbs/knot)			.570	.188	1.224	.649
101								
102		F-S (lbs)			592.84	357.02	557.05	169.84

	A	B C D	E	F	G	H
73	>>	R (d-tab / d-elev.)	.50	.50	.50	.50
74		C-h-dE (tab + elev.)	-.9800	-.8395	-.9800	-.8395
75						
76		alpha-o-trim (rad)	-.032	-.032	-.031	-.031
77		delta-o-trim (rad)	-.011	-.004	-.025	-.018
78						
79		d-alpha/dCL	.190	.187	.183	.181
80		d-dE/dCL	-.141	-.141	-.056	-.059
81						
82		alpha-trim (rad)	.005	.121	.003	.109
83		del-E-trim (rad)	-.038	-.120	-.035	-.064
84						
85	>>	Load Factor (g's)	1.00	1.00	1.00	1.00
86		d-delE/dV (rad/fps)	7.86e-5	1.11e-3	2.96e-5	4.353e-4
87		d-delE/dn (rad/g)	-.036	-.212	-.018	-.135
88						
89		c-h	.0360	.0789	.0340	.0341
90						
91		S.M.(FREE)	.164	.183	.031	.049
92						
93		dF/dn (lbs/g)	230.32	261.27	67.95	123.84
94						
95		dF/dn MIN	23.33	23.33	23.33	23.33
96		dF/dn MAX	80.00	80.00	80.00	80.00
97						
98		Passes MIL-F-8785C	no	no	yes	no
99						
100		dF/dV (lbs/knot)	.401	.132	.829	.416
101						
102		F-S (lbs)	384.66	200.29	363.16	86.50

Row	A	B	E	F	G	H
73	>>	R (d-tab / d-elev.)	-.50	-.50	-.50	-.50
74		C-h-dE (tab + elev.)	.0420	.1935	.0420	.1935
75						
76		alpha-o-trim (rad)	-.032	-.032	-.031	-.031
77		delta-o-trim (rad)	-.011	-.004	-.025	-.018
78						
79		d-alpha/dCL	.190	.187	.183	.181
80		d-dE/dCL	-.141	-.141	-.056	-.059
81						
82		alpha-trim (rad)	.005	.121	.003	.109
83		del-E-trim (rad)	-.038	-.120	-.035	-.064
84						
85	>>	Load Factor (g's)	1.00	1.00	1.00	1.00
86		d-delE/dV (rad/fps)	7.86e-5	1.11e-3	2.96e-5	4.353e-4
87		d-delE/dn (rad/g)	-.036	-.212	-.018	-.135
88						
89		c-h	-.0030	-.0446	-.0023	-.0316
90						
91		S.M.(FREE)	1.633	.440	1.450	.298
92						
93		dF/dn (lbs/g)	-91.69	-131.94	-80.36	-96.59
94						
95		dF/dn MIN	23.33	23.33	23.33	23.33
96		dF/dn MAX	80.00	80.00	80.00	80.00
97						
98		Passes MIL-F-8785C	no	no	no	no
99						
100		dF/dV (lbs/knot)	.064	.021	.038	-.049
101						
102		F-S (lbs)	-31.70	-113.16	-24.61	-80.20

	A	B	C	D	E	F	G	H
73	>>	R (d-tab / d-elev.)			-1.00	-1.00	-1.00	-1.00
74		C-h-dE (tab + elev.)			.5530	.7100	.5530	.7100
75								
76		alpha-o-trim (rad)			-.032	-.032	-.031	-.031
77		delta-o-trim (rad)			-.011	-.004	-.025	-.018
78								
79		d-alpha/dCL			.190	.187	.183	.181
80		d-dE/dCL			-.141	-.141	-.056	-.059
81								
82		alpha-trim (rad)			.005	.121	.003	.109
83		del-E-trim (rad)			-.038	-.120	-.035	-.064
84								
85	>>	Load Factor (g's)			1.00	1.00	1.00	1.00
86		d-delE/dV (rad/fps)			7.86e-5	1.11e-3	2.96e-5	4.353e-4
87		d-delE/dn (rad/g)			-.036	-.212	-.018	-.135
88								
89		c-h			-.0224	-.1063	-.0204	-.0644
90								
91		S.M.(FREE)			.331	.288	.192	.151
92								
93		dF/dn (lbs/g)			-252.69	-328.55	-154.52	-206.80
94								
95		dF/dn MIN			23.33	23.33	23.33	23.33
96		dF/dn MAX			80.00	80.00	80.00	80.00
97								
98		Passes MIL-F-8785C			no	no	no	no
99								
100		dF/dV (lbs/knot)			-.105	-.035	-.357	-.282
101								
102		F-S (lbs)			-239.88	-269.89	-218.50	-163.54

36 Pax Stick Force Calculations

	F.C. 1	F.C. 2	F.C. 3	F.C. 4
	Fwd c.g. Cruise	Fwd c.g. Vmc	Aft c.g. Cruise	Aft c.g. Vmc
h (ft)	30000	0	30000	0
density (slugs/ft3)	8.893e-4	2.377e-3	8.893e-4	2.377e-3
V (fps)	696.3	207.5	696.3	207.5
q-bar (psf)	215.58	51.17	215.58	51.17
X-bar-AC	.454	.454	.454	.454
X-bar-cg	.267	.267	.385	.385

Geometries, Inertias

S (ft2)	592	592	592	592
b (ft)	84.30	84.30	84.30	84.30
c-bar (ft)	7.45	7.45	7.45	7.45
W (lb)	30334	30334	28574	28574
Ixx (slug-ft2)	70773	70773	124022	124022
Iyy (slug-ft2)	235569	235569	209114	109114
Izz (slug-ft2)	284424	284424	310361	310361

Steady State Coefficients

CL	.238	1.001	.224	.943
CD	.0177	.1690	.0175	.1690

Longitudinal Derivatives

C-L-a-A (rad-1)	5.58	5.67	5.58	5.67
C-m-dE (rad-1)	-1.85	-1.91	-1.80	-1.86
C-L-o	.170	.170	.170	.170
C-m-o	-.006	.005	-.006	.005
C-L-dE (rad-1)	.420	.434	.420	.434
C-L-i-H (rad-1)	.778	.803	.778	.803
C-m-i-H (rad-1)	-3.431	-3.540	-3.340	-3.445
C-m-alpha (rad-1)	-1.041	-1.098	-.383	-.429
C-m-q (rad-1)	-33.485	-34.540	-31.650	-32.650

Lateral-Directional Derivatives

	FC 1	FC 2	FC 3	FC 4
C-n-Beta (rad-1)	.118	.153	.118	.153
C-l-p	-.715	-.582	-.715	-.582
C-l-dA (rad-1)	.553	.455	.553	.455
C-n-dR (rad-1)	.088	.100	.088	.100

Longitudinal Stick Force Calculations

››	Eta-H	1.00	1.00	1.00	1.00
››	Gearing Ratio (rad/ft)	.72	.72	.72	.72
››	S-Elev. (ft2)	42.00	42.00	42.00	42.00
››	C-Elev. (ft)	1.640	1.640	1.640	1.640
››	C-h-dE (rad-1)	-.469	-.323	-.469	-.323
››	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
››	S-tab (ft2)	7.000	7.000	7.000	7.000
››	C-tab (ft)	.570	.570	.570	.570
››	C-h-alpha (rad-1)	-.263	-.177	-.263	-.177
››	1-H (ft)	32.85	32.85	31.97	32.85
››	Tau-E	.54	.54	.54	.54
››	i-H (deg)	.00	.00	.00	.00
	dE/da	.254	.254	.254	.254
››	n/alpha (g/rad)	23.48	5.57	24.92	5.92
	n-Limit	2.50	2.50	2.50	2.50
››	R (d-tab / d-elev.)	.00	.00	.00	.00
	C-h-dE (tab + elev.)	-.4690	-.3230	-.4690	-.3230
	alpha-o-trim (rad)	-.032	-.032	-.031	-.031
	delta-o-trim (rad)	.014	.021	.003	.010
	d-alpha/dCL	.187	.184	.182	.180
	d-dE/dCL	-.105	-.106	-.039	-.041
	alpha-trim (rad)	.013	.153	.010	.139
	del-E-trim (rad)	-.010	-.085	-.005	-.029
››	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	7.18e-5	1.0224e-3	2.49e-5	3.765e-4
	d-delE/dn (rad/g)	-.034	-.211	-.017	-.139
	c-h	.0015	.0005	-.0001	-.0151
	S.M.(FREE)	.048	.049	-.066	-.065
	dF/dn (lbs/g)	45.03	47.36	-27.47	-.81
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	89.77	80.00	84.53
	Passes MIL-F-8785C	yes	yes	no	no
	dF/dV (lbs/knot)	-.019	-.062	.139	.022
	F-S (lbs)	16.30	1.16	-.91	-38.26

A	B C D	E	F	G	H
	Longitudinal Stick Force Calculations				
>>	Eta-H	1.00	1.00	1.00	1.00
>>	Gearing Ratio (rad/ft)	.72	.72	.72	.72
>>	S-Elev. (ft2)	42.00	42.00	42.00	42.00
>>	C-Elev. (ft)	1.640	1.640	1.640	1.640
>>	C-h-dE (rad-1)	-.469	-.323	-.469	-.323
>>	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
>>	S-tab (ft2)	7.000	7.000	7.000	7.000
>>	C-tab (ft)	.570	.570	.570	.570
>>	C-h-alpha (rad-1)	-.263	-.177	-.263	-.177
>>	l-H (ft)	32.85	32.85	31.97	32.85
>>	Tau-E	.54	.54	.54	.54
>>	i-H (deg)	.00	.00	.00	.00
	dE/da	.254	.254	.254	.254
>>	n/alpha (g/rad)	23.48	5.57	24.92	5.92
	n-Limit	2.50	2.50	2.50	2.50
>>	R (d-tab / d-elev.)	1.00	1.00	1.00	1.00
	C-h-dE (tab + elev.)	-1.4910	-1.3560	-1.4910	-1.3560
	alpha-o-trim (rad)	-.032	-.032	-.031	-.031
	delta-o-trim (rad)	.014	.021	.003	.010
	d-alpha/dCL	.187	.184	.182	.180
	d-dE/dCL	-.105	-.106	-.039	-.041
	alpha-trim (rad)	.013	.153	.010	.139
	del-E-trim (rad)	-.010	-.085	-.005	-.029
>>	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	7.18e-5	1.0224e-3	2.49e-5	3.765e-4
	d-delE/dn (rad/g)	-.034	-.211	-.017	-.139
	c-h	.0123	.0886	.0055	.0152
	S.M.(FREE)	.143	.154	.026	.037
	dF/dn (lbs/g)	351.27	423.36	109.11	210.19
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	89.77	80.00	84.53
	Passes MIL-F-8785C	no	no	no	no
	dF/dV (lbs/knot)	-.473	-.586	.039	-.225
	F-S (lbs)	131.00	224.86	58.83	38.50

Longitudinal Stick Force Calculations

A	B C D	E	F	G	H
))	Eta-H	1.00	1.00	1.00	1.00
))	Gearing Ratio (rad/ft)	.72	.72	.72	.72
))	S-Elev. (ft2)	42.00	42.00	42.00	42.00
))	C-Elev. (ft)	1.640	1.640	1.640	1.640
))	C-h-dE (rad-1)	-.469	-.323	-.469	-.323
))	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
))	S-tab (ft2)	7.000	7.000	7.000	7.000
))	C-tab (ft)	.570	.570	.570	.570
))	C-h-alpha (rad-1)	-.263	-.177	-.263	-.177
))	l-H (ft)	32.85	32.85	31.97	32.85
))	Tau-E	.54	.54	.54	.54
))	i-H (deg)	.00	.00	.00	.00
	dE/da	.254	.254	.254	.254
))	n/alpha (g/rad)	23.48	5.57	24.92	5.92
	n-Limit	2.50	2.50	2.50	2.50
))	R (d-tab / d-elev.)	.50	.50	.50	.50
	C-h-dE (tab + elev.)	-.9800	-.8395	-.9800	-.8395
	alpha-o-trim (rad)	-.032	-.032	-.031	-.031
	delta-o-trim (rad)	.014	.021	.003	.010
	d-alpha/dCL	.187	.184	.182	.180
	d-dE/dCL	-.105	-.106	-.039	-.041
	alpha-trim (rad)	.013	.153	.010	.139
	del-E-trim (rad)	-.010	-.085	-.005	-.029
))	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	7.18e-5	1.0224e-3	2.49e-5	3.765e-4
	d-delE/dn (rad/g)	-.034	-.211	-.017	-.139
	c-h	.0069	.0445	.0027	.0000
	S.M.(FREE)	.121	.134	.004	.017
	dF/dn (lbs/g)	198.15	235.36	40.82	104.69
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	89.77	80.00	84.53
	Passes MIL-F-8785C	no	no	yes	no
	dF/dV (lbs/knot)	-.246	-.324	.089	-.101
	F-S (lbs)	73.65	113.01	28.96	.12

Longitudinal Stick Force Calculations

A	B C D	E	F	G	H
>>	Eta-H	1.00	1.00	1.00	1.00
>>	Gearing Ratio (rad/ft)	.72	.72	.72	.72
>>	S-Elev. (ft2)	42.00	42.00	42.00	42.00
>>	C-Elev. (ft)	1.640	1.640	1.640	1.640
>>	C-h-dE (rad-1)	-.469	-.323	-.469	-.323
>>	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
>>	S-tab (ft2)	7.000	7.000	7.000	7.000
>>	C-tab (ft)	.570	.570	.570	.570
>>	C-h-alpha (rad-1)	-.263	-.177	-.263	-.177
>>	l-H (ft)	32.85	32.85	31.97	32.85
>>	Tau-E	.54	.54	.54	.54
>>	i-H (deg)	.00	.00	.00	.00
	dE/da	.254	.254	.254	.254
>>	n/alpha (g/rad)	23.48	5.57	24.92	5.92
	n-Limit	2.50	2.50	2.50	2.50
>>	R (d-tab / d-elev.)	-.50	-.50	-.50	-.50
	C-h-dE (tab + elev.)	.0420	.1935	.0420	.1935
	alpha-o-trim (rad)	-.032	-.032	-.031	-.031
	delta-o-trim (rad)	.014	.021	.003	.010
	d-alpha/dCL	.187	.184	.182	.180
	d-dE/dCL	-.105	-.106	-.039	-.041
	alpha-trim (rad)	.013	.153	.010	.139
	del-E-trim (rad)	-.010	-.085	-.005	-.029
>>	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	7.18e-5	1.0224e-3	2.49e-5	3.765e-4
	d-delE/dn (rad/g)	-.034	-.211	-.017	-.139
	c-h	-.0038	-.0436	-.0029	-.0302
	S.M.(FREE)	1.739	.417	1.579	.293
	dF/dn (lbs/g)	-108.09	-140.65	-95.76	-106.30
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	89.77	80.00	84.53
	Passes MIL-F-8785C	no	no	no	no
	dF/dV (lbs/knot)	.209	.200	.189	.146
	F-S (lbs)	-41.05	-110.70	-30.77	-76.64

Longitudinal Stick Force Calculations

A	B C D	E	F	G	H
>>	Eta-H	1.00	1.00	1.00	1.00
>>	Gearing Ratio (rad/ft)	.72	.72	.72	.72
>>	S-Elev. (ft2)	42.00	42.00	42.00	42.00
>>	C-Elev. (ft)	1.640	1.640	1.640	1.640
>>	C-h-dE (rad-1)	-.469	-.323	-.469	-.323
>>	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
>>	S-tab (ft2)	7.000	7.000	7.000	7.000
>>	C-tab (ft)	.570	.570	.570	.570
>>	C-h-alpha (rad-1)	-.263	-.177	-.263	-.177
>>	l-H (ft)	32.85	32.85	31.97	32.85
>>	Tau-E	.54	.54	.54	.54
>>	i-H (deg)	.00	.00	.00	.00
	dE/da	.254	.254	.254	.254
>>	n/alpha (g/rad)	23.48	5.57	24.92	5.92
	n-Limit	2.50	2.50	2.50	2.50
>>	R (d-tab / d-elev.)	-1.00	-1.00	-1.00	-1.00
	C-h-dE (tab + elev.)	.5530	.7100	.5530	.7100
	alpha-o-trim (rad)	-.032	-.032	-.031	-.031
	delta-o-trim (rad)	.014	.021	.003	.010
	d-alpha/dCL	.187	.184	.182	.180
	d-dE/dCL	-.105	-.106	-.039	-.041
	alpha-trim (rad)	.013	.153	.010	.139
	del-E-trim (rad)	-.010	-.085	-.005	-.029
>>	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	7.18e-5	1.0224e-3	2.49e-5	3.765e-4
	d-delE/dn (rad/g)	-.034	-.211	-.017	-.139
	c-h	-.0092	-.0877	-.0057	-.0453
	S.M.(FREE)	.305	.250	.184	.130
	dF/dn (lbs/g)	-261.20	-328.65	-164.06	-211.80
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	89.77	80.00	84.53
	Passes MIL-F-8785C	no	no	no	no
	dF/dV (lbs/knot)	.436	.462	.239	.269
	F-S (lbs)	-98.40	-222.55	-60.64	-115.03

A B C D E F G H

50 Pax Stick Force Calculations

	F.C. 1	F.C. 2	F.C. 3	F.C. 4
	Fwd c.g. Cruise	Fwd c.g. Vmc	Aft c.g. Cruise	Aft c.g. Vmc
h (ft)	30000	0	30000	0
density (slugs/ft3)	8.893e-4	2.377e-3	8.893e-4	2.377e-3
V (fps)	696.3	207.5	696.3	207.5
q-bar (psf)	215.58	51.17	215.58	51.17
X-bar-AC	.664	.673	.664	.673
X-bar-cg	.530	.530	.603	.603
Geometries, Inertias				
S (ft2)	592	592	592	592
b (ft)	84.30	84.30	84.30	84.30
c-bar (ft)	7.45	7.45	7.45	7.45
W (lb)	43141	43141	25978	25978
Ixx (slug-ft2)	141865	141865	73363	73363
Iyy (slug-ft2)	465510	465510	408670	408670
Izz (slug-ft2)	580046	580046	457113	457113
Steady State Coefficients				
CL	.338	1.424	.204	.858
CD	.0191	.2029	.0169	.2029
Longitudinal Derivatives				
C-L-a-A (rad-1)	5.58	5.67	5.58	5.67
C-m-dE (rad-1)	-2.32	-2.39	-2.29	-2.36
C-L-o	.170	.170	.170	.170
C-m-o	.017	.028	.017	.028
C-L-dE (rad-1)	.420	.434	.420	.434
C-L-i-H (rad-1)	.778	.803	.778	.803
C-m-i-H (rad-1)	-4.288	-4.424	-4.231	-4.365
C-m-alpha (rad-1)	-.749	-.808	-.341	-.395
C-m-q (rad-1)	-53.652	-55.310	-52.137	-53.747
	FC 1	FC 2	FC 3	FC 4
Lateral-Directional Derivatives				
C-n-Beta (rad-1)	.197	.237	.197	.237
C-l-p	-.715	-.582	-.715	-.582
C-l-dA (rad-1)	.553	.455	.553	.455
C-n-dR (rad-1)	.116	.129	.116	.129

Longitudinal Stick Force Calculations

>>	Eta-H	1.00	1.00	1.00	1.00
>>	Gearing Ratio (rad/ft)	.72	.72	.72	.72
>>	S-Elev. (ft2)	42.00	42.00	42.00	42.00
>>	C-Elev. (ft)	1.640	1.640	1.640	1.640
>>	C-h-dE (rad-1)	-.469	-.323	-.469	-.323
>>	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
>>	S-tab (ft2)	7.000	7.000	7.000	7.000
>>	C-tab (ft)	.570	.570	.570	.570
>>	C-h-alpha (rad-1)	-.263	-.177	-.263	-.177
>>	l-H (ft)	41.05	41.05	40.50	41.05
>>	Tau-E	.54	.54	.54	.54
>>	i-H (deg)	.00	.00	.00	.00
	dE/da	.254	.254	.254	.254
>>	n/alpha (g/rad)	16.51	3.92	27.41	6.51
	n-Limit	2.50	2.50	2.50	2.50
>>	R (d-tab / d-elev.)	.00	.00	.00	.00
	C-h-dE (tab + elev.)	-.4690	-.3230	-.4690	-.3230
	alpha-o-trim (rad)	-.032	-.032	-.031	-.031
	delta-o-trim (rad)	.018	.022	.012	.017
	d-alpha/dCL	.184	.181	.181	.179
	d-dE/dCL	-.059	-.061	-.027	-.030
	alpha-trim (rad)	.030	.226	.006	.122
	del-E-trim (rad)	-.002	-.065	.007	-.009
>>	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	5.77e-5	8.405e-4	1.58e-5	2.475e-4
	d-delE/dn (rad/g)	-.032	-.220	-.017	-.154
	c-h	-.0068	-.0191	-.0046	-.0188
	S.M. (FREE)	-.040	-.029	-.110	-.100
	dF/dn (lbs/g)	-11.38	18.52	-31.87	3.01
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	120.00	80.00	80.00
	Passes MIL-F-8785C	no	no	no	no
	dF/dV (lbs/knot)	-.062	-.075	.014	-.034
	F-S (lbs)	-72.87	-48.49	-48.69	-47.75

Longitudinal Stick Force Calculations

A	B C D	E	F	G	H
>>	Eta-H	1.00	1.00	1.00	1.00
>>	Gearing Ratio (rad/ft)	.72	.72	.72	.72
>>	S-Elev. (ft2)	42.00	42.00	42.00	42.00
>>	C-Elev. (ft)	1.640	1.640	1.640	1.640
>>	C-h-dE (rad-1)	-.469	-.323	-.469	-.323
>>	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
>>	S-tab (ft2)	7.000	7.000	7.000	7.000
>>	C-tab (ft)	.570	.570	.570	.570
>>	C-h-alpha (rad-1)	-.263	-.177	-.263	-.177
>>	l-H (ft)	41.05	41.05	40.50	41.05
>>	Tau-E	.54	.54	.54	.54
>>	i-H (deg)	.00	.00	.00	.00
	dE/da	.254	.254	.254	.254
>>	n/alpha (g/rad)	16.51	3.92	27.41	6.51
	n-Limit	2.50	2.50	2.50	2.50
>>	R (d-tab / d-elev.)	1.00	1.00	1.00	1.00
	C-h-dE (tab + elev.)	-1.4910	-1.3560	-1.4910	-1.3560
	alpha-o-trim (rad)	-.032	-.032	-.031	-.031
	delta-o-trim (rad)	.018	.022	.012	.017
	d-alpha/dCL	.184	.181	.181	.179
	d-dE/dCL	-.059	-.061	-.027	-.030
	alpha-trim (rad)	.030	.226	.006	.122
	del-E-trim (rad)	-.002	-.065	.007	-.009
>>	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	5.77e-5	8.405e-4	1.58e-5	2.475e-4
	d-delE/dn (rad/g)	-.032	-.220	-.017	-.154
	c-h	-.0043	.0478	-.0113	-.0100
	S.M. (FREE)	.079	.102	.007	.030
	dF/dn (lbs/g)	257.49	391.03	81.93	218.81
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	120.00	80.00	80.00
	Passes MIL-F-8785C	no	no	no	no
	dF/dV (lbs/knot)	-.615	-.642	-.366	-.467
	F-S (lbs)	-45.99	121.29	-120.99	-25.33

Longitudinal Stick Force Calculations

A	B	C	D	E	F	G	H
>>	Eta-H			1.00	1.00	1.00	1.00
>>	Gearing Ratio (rad/ft)			.72	.72	.72	.72
>>	S-Elev. (ft2)			42.00	42.00	42.00	42.00
>>	C-Elev. (ft)			1.640	1.640	1.640	1.640
>>	C-h-dE (rad-1)			-.469	-.323	-.469	-.323
>>	C-h-d-tab (rad-1)			-1.022	-1.033	-1.022	-1.033
>>	S-tab (ft2)			7.000	7.000	7.000	7.000
>>	C-tab (ft)			.570	.570	.570	.570
>>	C-h-alpha (rad-1)			-.263	-.177	-.263	-.177
>>	l-H (ft)			41.05	41.05	40.50	41.05
>>	Tau-E			.54	.54	.54	.54
>>	i-H (deg)			.00	.00	.00	.00
	dE/da			.254	.254	.254	.254
>>	n/alpha (g/rad)			16.51	3.92	27.41	6.51
	n-Limit			2.50	2.50	2.50	2.50
>>	R (d-tab / d-elev.)			.50	.50	.50	.50
	C-h-dE (tab + elev.)			-.9800	-.8395	-.9800	-.8395
	alpha-o-trim (rad)			-.032	-.032	-.031	-.031
	delta-o-trim (rad)			.018	.022	.012	.017
	d-alpha/dCL			.184	.181	.181	.179
	d-dE/dCL			-.059	-.061	-.027	-.030
	alpha-trim (rad)			.030	.226	.006	.122
	del-E-trim (rad)			-.002	-.065	.007	-.009
>>	Load Factor (g's)			1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)			5.77e-5	8.405e-4	1.58e-5	2.475e-4
	d-delE/dn (rad/g)			-.032	-.220	-.017	-.154
	c-h			-.0056	.0143	-.0079	-.0144
	S.M.(FREE)			.051	.077	-.021	.005
	dF/dn (lbs/g)			123.06	204.78	25.03	110.91
	dF/dn MIN			23.33	23.33	23.33	23.33
	dF/dn MAX			80.00	120.00	80.00	80.00
	Passes MIL-F-8785C			no	no	yes	no
	dF/dV (lbs/knot)			-.339	-.358	-.176	-.251
	F-S (lbs)			-59.43	36.40	-84.84	-36.54

A	B	C	D	E	F	G	H
	Longitudinal Stick Force Calculations						
>>	Eta-H			1.00	1.00	1.00	1.00
>>	Gearing Ratio (rad/ft)			.72	.72	.72	.72
>>	S-Elev. (ft2)			42.00	42.00	42.00	42.00
>>	C-Elev. (ft)			1.640	1.640	1.640	1.640
>>	C-h-dE (rad-1)			-.469	-.323	-.469	-.323
>>	C-h-d-tab (rad-1)			-1.022	-1.033	-1.022	-1.033
>>	S-tab (ft2)			7.000	7.000	7.000	7.000
>>	C-tab (ft)			.570	.570	.570	.570
>>	C-h-alpha (rad-1)			-.263	-.177	-.263	-.177
>>	l-H (ft)			41.05	41.05	40.50	41.05
>>	Tau-E			.54	.54	.54	.54
>>	i-H (deg)			.00	.00	.00	.00
	dE/da			.254	.254	.254	.254
>>	n/alpha (g/rad)			16.51	3.92	27.41	6.51
	n-Limit			2.50	2.50	2.50	2.50
>>	R (d-tab / d-elev.)			-.50	-.50	-.50	-.50
	C-h-dE (tab + elev.)			.0420	.1935	.0420	.1935
	alpha-o-trim (rad)			-.032	-.032	-.031	-.031
	delta-o-trim (rad)			.018	.022	.012	.017
	d-alpha/dCL			.184	.181	.181	.179
	d-dE/dCL			-.059	-.061	-.027	-.030
	alpha-trim (rad)			.030	.226	.006	.122
	del-E-trim (rad)			-.002	-.065	.007	-.009
>>	Load Factor (g's)			1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)			5.77e-5	8.405e-4	1.58e-5	2.475e-4
	d-delE/dn (rad/g)			-.032	-.220	-.017	-.154
	c-h			-.0081	-.0526	-.0012	-.0232
	S.M. (FREE)			2.073	.431	1.974	.354
	dF/dn (lbs/g)			-145.81	-167.73	-88.77	-104.89
	dF/dn MIN			23.33	23.33	23.33	23.33
	dF/dn MAX			80.00	120.00	80.00	80.00
	Passes MIL-F-8785C			no	no	no	no
	dF/dV (lbs/knot)			.214	.209	.205	.182
	F-S (lbs)			-86.31	-133.38	-12.54	-58.96

	A	B–D	E	F	G	H
53		Longitudinal Stick Force Calculations				
55	>>	Eta-H	1.00	1.00	1.00	1.00
56	>>	Gearing Ratio (rad/ft)	.72	.72	.72	.72
57	>>	S-Elev. (ft2)	42.00	42.00	42.00	42.00
58	>>	C-Elev. (ft)	1.640	1.640	1.640	1.640
59	>>	C-h-dE (rad-1)	-.469	-.323	-.469	-.323
61	>>	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
63	>>	S-tab (ft2)	7.000	7.000	7.000	7.000
64	>>	C-tab (ft)	.570	.570	.570	.570
65	>>	C-h-alpha (rad-1)	-.263	-.177	-.263	-.177
66	>>	l-H (ft)	41.05	41.05	40.50	41.05
67	>>	Tau-E	.54	.54	.54	.54
68	>>	i-H (deg)	.00	.00	.00	.00
69		dE/da	.254	.254	.254	.254
70	>>	n/alpha (g/rad)	16.51	3.92	27.41	6.51
71		n-Limit	2.50	2.50	2.50	2.50
73	>>	R (d-tab / d-elev.)	-1.00	-1.00	-1.00	-1.00
74		C-h-dE (tab + elev.)	.5530	.7100	.5530	.7100
76		alpha-o-trim (rad)	-.032	-.032	-.031	-.031
77		delta-o-trim (rad)	.018	.022	.012	.017
79		d-alpha/dCL	.184	.181	.181	.179
80		d-dE/dCL	-.059	-.061	-.027	-.030
82		alpha-trim (rad)	.030	.226	.006	.122
83		del-E-trim (rad)	-.002	-.065	.007	-.009
85	>>	Load Factor (g's)	1.00	1.00	1.00	1.00
86		d-delE/dV (rad/fps)	5.77e-5	8.405e-4	1.58e-5	2.475e-4
87		d-delE/dn (rad/g)	-.032	-.220	-.017	-.154
89		c-h	-.0093	-.0860	.0022	-.0276
91		S.M. (FREE)	.281	.221	.206	.147
93		dF/dn (lbs/g)	-280.25	-353.98	-145.67	-212.80
95		dF/dn MIN	23.33	23.33	23.33	23.33
96		dF/dn MAX	80.00	120.00	80.00	80.00
98		Passes MIL-F-8785C	no	no	no	no
100		dF/dV (lbs/knot)	.491	.492	.395	.398
102		F-S (lbs)	-99.75	-218.27	23.61	-70.17

A B C D E F G H

5/21/1987

75 Pax Baseline Stick Force Calculations

	F.C. 1	F.C. 2	F.C. 3	F.C. 4
	Fwd c.g. Cruise	Fwd c.g. Vmc	Aft c.g. Cruise	Aft c.g. Vmc
h (ft)	30000	0	30000	0
density (slugs/ft3)	8.893e-4	2.377e-3	8.893e-4	2.377e-3
V (fps)	696.3	207.5	696.3	207.5
q-bar (psf)	215.58	51.17	215.58	51.17
X-bar-AC	.821	.813	.821	.813
X-bar-cg	.602	.602	.769	.769
Geometries, Inertias				
S (ft2)	1182	1182	1182	1182
b (ft)	132.50	132.50	132.50	132.50
c-bar (ft)	8.97	8.97	8.97	8.97
W (lb)	71419	71419	44804	44804
Ixx (slug-ft2)	1355496	1355496	761328	761328
Iyy (slug-ft2)	505928	505928	441252	441252
Izz (slug-ft2)	1779110	1779110	1125135	1125135
Steady State Coefficients				
CL	.280	1.181	.176	.741
CD	.016	.224	.015	.223
Longitudinal Derivatives				
C-L-a-A (rad-1)	6.53	6.60	6.53	6.60
C-m-dE (rad-1)	-3.41	-3.42	-3.26	-3.26
C-L-o	.170	.170	.170	.170
C-m-o	.081	.090	.081	.090
C-L-dE (rad-1)	.927	.928	.927	.928
C-L-i-H (rad-1)	1.716	1.718	1.716	1.718
C-m-i-H (rad-1)	-6.317	-6.324	-6.031	-6.037
C-m-alpha (rad-1)	-1.430	-1.394	-.339	-.292
C-m-q (rad-1)	-51.250	-51.308	-46.651	-46.704
	FC 1	FC 2	FC 3	FC 4
Lateral-Directional Derivatives				
C-n-Beta (rad-1)	.034	.055	.034	.055
C-l-p	-.792	-.632	-.792	-.632
C-l-dA (rad-1)	.608	.443	.608	.443
C-n-dR (rad-1)	.053	.060	.053	.060

Longitudinal Stick Force Calculations

))	Eta-H	1.00	1.00	1.00	1.00
))	Gearing Ratio (rad/ft)	.72	.72	.72	.72
))	S-Elev. (ft2)	143.50	143.50	143.50	143.50
))	C-Elev. (ft)	1.640	1.640	1.640	1.640
))	C-h-dE (rad-1)	-.598	-.422	-.598	-.422
))	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
))	S-tab (ft2)	7.000	7.000	7.000	7.000
))	C-tab (ft)	.570	.570	.570	.570
))	C-h-alpha (rad-1)	-.346	-.241	-.346	-.241
))	l-H (ft)	33.02	33.02	31.52	31.52
))	Tau-E	.54	.54	.54	.54
))	i-H (deg)	.00	.00	.00	.00
	dE/da	.214	.214	.214	.214
))	n/alpha (g/rad)	23.32	5.53	37.17	8.82
	n-Limit	2.50	2.50	2.50	2.50
))	R (d-tab / d-elev.)	.00	.06	2.30	1.78
	C-h-dE (tab + elev.)	-.5980	-.4840	-2.9486	-2.2607
	alpha-o-trim (rad)	-.031	-.031	-.030	-.030
	delta-o-trim (rad)	.037	.039	.028	.030
	d-alpha/dCL	.163	.161	.155	.154
	d-dE/dCL	-.068	-.066	-.016	-.014
	alpha-trim (rad)	.014	.159	-.003	.084
	del-E-trim (rad)	.018	-.038	.025	.020
))	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	5.49e-5	7.472e-4	8.2e-6	9.82e-5
	d-delE/dn (rad/g)	-.029	-.184	-.012	-.108
	c-h	-.0156	-.0196	-.0732	-.0656
	S.M.(FREE)	-.018	.008	.006	.003
	dF/dn (lbs/g)	27.95	152.44	426.22	817.98
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	90.42	80.00	80.00
	Passes MIL-F-8785C	yes	no	no	no
	dF/dV (lbs/knot)	-1.420	-1.087	-7.807	-5.249
	F-S (lbs)	-568.73	-170.35	-2675.70	-569.12

A	B C D	E	F	G	H
	Longitudinal Stick Force Calculations				
>>	Eta-H	1.00	1.00	1.00	1.00
>>	Gearing Ratio (rad/ft)	.72	.72	.72	.72
>>	S-Elev. (ft2)	143.50	143.50	143.50	143.50
>>	C-Elev. (ft)	1.640	1.640	1.640	1.640
>>	C-h-dE (rad-1)	-.598	-.422	-.598	-.422
>>	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
>>	S-tab (ft2)	7.000	7.000	7.000	7.000
>>	C-tab (ft)	.570	.570	.570	.570
>>	C-h-alpha (rad-1)	-.346	-.241	-.346	-.241
>>	l-H (ft)	33.02	33.02	31.52	31.52
>>	Tau-E	.54	.54	.54	.54
>>	i-H (deg)	.00	.00	.00	.00
	dE/da	.214	.214	.214	.214
>>	n/alpha (g/rad)	23.32	5.53	37.17	8.82
	n-Limit	2.50	2.50	2.50	2.50
>>	R (d-tab / d-elev.)	.00	.00	.00	.00
	C-h-dE (tab + elev.)	-.5980	-.4220	-.5980	-.4220
	alpha-o-trim (rad)	-.031	-.031	-.030	-.030
	delta-o-trim (rad)	.037	.039	.028	.030
	d-alpha/dCL	.163	.161	.155	.154
	d-dE/dCL	-.068	-.066	-.016	-.014
	alpha-trim (rad)	.014	.159	-.003	.084
	del-E-trim (rad)	.018	-.038	.025	.020
>>	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	5.49e-5	7.472e-4	8.2e-6	9.82e-5
	d-delE/dn (rad/g)	-.029	-.184	-.012	-.108
	c-h	-.0156	-.0220	-.0141	-.0287
	S.M.(FREE)	-.018	-.021	-.175	-.178
	dF/dn (lbs/g)	27.95	88.65	-147.76	-37.40
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	90.42	80.00	80.00
	Passes MIL-F-8785C	yes	yes	no	no
	dF/dV (lbs/knot)	-1.420	-.885	-.901	-.593
	F-S (lbs)	-568.73	-190.99	-515.68	-248.49

Longitudinal Stick Force Calculations

A	B	E	F	G	H
>>	Eta-H	1.00	1.00	1.00	1.00
>>	Gearing Ratio (rad/ft)	.72	.72	.72	.72
>>	S-Elev. (ft2)	143.50	143.50	143.50	143.50
>>	C-Elev. (ft)	1.640	1.640	1.640	1.640
>>	C-h-dE (rad-1)	-.598	-.422	-.598	-.422
>>	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
>>	S-tab (ft2)	7.000	7.000	7.000	7.000
>>	C-tab (ft)	.570	.570	.570	.570
>>	C-h-alpha (rad-1)	-.346	-.241	-.346	-.241
>>	l-H (ft)	33.02	33.02	31.52	31.52
>>	Tau-E	.54	.54	.54	.54
>>	i-H (deg)	.00	.00	.00	.00
	dE/da	.214	.214	.214	.214
>>	n/alpha (g/rad)	23.32	5.53	37.17	8.82
	n-Limit	2.50	2.50	2.50	2.50
>>	R (d-tab / d-elev.)	1.00	1.00	1.00	1.00
	C-h-dE (tab + elev.)	-1.6200	-1.4550	-1.6200	-1.4550
	alpha-o-trim (rad)	-.031	-.031	-.030	-.030
	delta-o-trim (rad)	.037	.039	.028	.030
	d-alpha/dCL	.163	.161	.155	.154
	d-dE/dCL	-.068	-.066	-.016	-.014
	alpha-trim (rad)	.014	.159	-.003	.084
	del-E-trim (rad)	.018	-.038	.025	.020
>>	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	5.49e-5	7.472e-4	8.2e-6	9.82e-5
	d-delE/dn (rad/g)	-.029	-.184	-.012	-.108
	c-h	-.0337	.0176	-.0398	-.0494
	S.M.(FREE)	.131	.144	-.032	-.020
	dF/dn (lbs/g)	851.36	1151.72	101.79	443.15
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	90.42	80.00	80.00
	Passes MIL-F-8785C	no	no	no	no
	dF/dV (lbs/knot)	-5.371	-4.262	-3.904	-3.209
	F-S (lbs)	-1230.47	152.99	-1454.82	-428.62

Longitudinal Stick Force Calculations

A	B C D	E	F	G	H
>>	Eta-H	1.00	1.00	1.00	1.00
>>	Gearing Ratio (rad/ft)	.72	.72	.72	.72
>>	S-Elev. (ft2)	143.50	143.50	143.50	143.50
>>	C-Elev. (ft)	1.640	1.640	1.640	1.640
>>	C-h-dE (rad-1)	-.598	-.422	-.598	-.422
>>	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
>>	S-tab (ft2)	7.000	7.000	7.000	7.000
>>	C-tab (ft)	.570	.570	.570	.570
>>	C-h-alpha (rad-1)	-.346	-.241	-.346	-.241
>>	l-H (ft)	33.02	33.02	31.52	31.52
>>	Tau-E	.54	.54	.54	.54
>>	i-H (deg)	.00	.00	.00	.00
	dE/da	.214	.214	.214	.214
>>	n/alpha (g/rad)	23.32	5.53	37.17	8.82
	n-Limit	2.50	2.50	2.50	2.50
>>	R (d-tab / d-elev.)	.50	.50	.50	.50
	C-h-dE (tab + elev.)	-1.1090	-.9385	-1.1090	-.9385
	alpha-o-trim (rad)	-.031	-.031	-.030	-.030
	delta-o-trim (rad)	.037	.039	.028	.030
	d-alpha/dCL	.163	.161	.155	.154
	d-dE/dCL	-.068	-.066	-.016	-.014
	alpha-trim (rad)	.014	.159	-.003	.084
	del-E-trim (rad)	.018	-.038	.025	.020
>>	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	5.49e-5	7.472e-4	8.2e-6	9.82e-5
	d-delE/dn (rad/g)	-.029	-.184	-.012	-.108
	c-h	-.0246	-.0022	-.0270	-.0390
	S.M. (FREE)	.091	.107	-.070	-.056
	dF/dn (lbs/g)	439.65	620.19	-22.99	202.88
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	90.42	80.00	80.00
	Passes MIL-F-8785C	no	no	no	no
	dF/dV (lbs/knot)	-3.396	-2.573	-2.402	-1.901
	F-S (lbs)	-899.60	-19.00	-985.25	-338.55

A	B C D	E	F	G	H
	Longitudinal Stick Force Calculations				
>>	Eta-H	1.00	1.00	1.00	1.00
>>	Gearing Ratio (rad/ft)	.72	.72	.72	.72
>>	S-Elev. (ft2)	143.50	143.50	143.50	143.50
>>	C-Elev. (ft)	1.640	1.640	1.640	1.640
>>	C-h-dE (rad-1)	-.598	-.422	-.598	-.422
>>	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
>>	S-tab (ft2)	7.000	7.000	7.000	7.000
>>	C-tab (ft)	.570	.570	.570	.570
>>	C-h-alpha (rad-1)	-.346	-.241	-.346	-.241
>>	l-H (ft)	33.02	33.02	31.52	31.52
>>	Tau-E	.54	.54	.54	.54
>>	i-H (deg)	.00	.00	.00	.00
	dE/da	.214	.214	.214	.214
>>	n/alpha (g/rad)	23.32	5.53	37.17	8.82
	n-Limit	2.50	2.50	2.50	2.50
>>	R (d-tab / d-elev.)	-.50	-.50	-.50	-.50
	C-h-dE (tab + elev.)	-.0870	.0945	-.0870	.0945
	alpha-o-trim (rad)	-.031	-.031	-.030	-.030
	delta-o-trim (rad)	.037	.039	.028	.030
	d-alpha/dCL	.163	.161	.155	.154
	d-dE/dCL	-.068	-.066	-.016	-.014
	alpha-trim (rad)	.014	.159	-.003	.084
	del-E-trim (rad)	.018	-.038	.025	.020
>>	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	5.49e-5	7.472e-4	8.2e-6	9.82e-5
	d-delE/dn (rad/g)	-.029	-.184	-.012	-.108
	c-h	-.0065	-.0419	-.0013	-.0183
	S.M. (FREE)	-1.413	1.249	-1.506	1.035
	dF/dn (lbs/g)	-383.75	-442.88	-272.54	-277.67
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	90.42	80.00	80.00
	Passes MIL-F-8785C	no	no	no	no
	dF/dV (lbs/knot)	.555	.804	.600	.715
	F-S (lbs)	-237.86	-362.98	-46.11	-158.42

Longitudinal Stick Force Calculations

A	B C D	E	F	G	H
>>	Eta-H	1.00	1.00	1.00	1.00
>>	Gearing Ratio (rad/ft)	.72	.72	.72	.72
>>	S-Elev. (ft2)	143.50	143.50	143.50	143.50
>>	C-Elev. (ft)	1.640	1.640	1.640	1.640
>>	C-h-dE (rad-1)	-.598	-.422	-.598	-.422
>>	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
>>	S-tab (ft2)	7.000	7.000	7.000	7.000
>>	C-tab (ft)	.570	.570	.570	.570
>>	C-h-alpha (rad-1)	-.346	-.241	-.346	-.241
>>	l-H (ft)	33.02	33.02	31.52	31.52
>>	Tau-E	.54	.54	.54	.54
>>	i-H (deg)	.00	.00	.00	.00
	dE/da	.214	.214	.214	.214
>>	n/alpha (g/rad)	23.32	5.53	37.17	8.82
	n-Limit	2.50	2.50	2.50	2.50
>>	R (d-tab / d-elev.)	-1.00	-1.00	-1.00	-1.00
	C-h-dE (tab + elev.)	.4240	.6110	.4240	.6110
	alpha-o-trim (rad)	-.031	-.031	-.030	-.030
	delta-o-trim (rad)	.037	.039	.028	.030
	d-alpha/dCL	.163	.161	.155	.154
	d-dE/dCL	-.068	-.066	-.016	-.014
	alpha-trim (rad)	.014	.159	-.003	.084
	del-E-trim (rad)	.018	-.038	.025	.020
>>	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	5.49e-5	7.472e-4	8.2e-6	9.82e-5
	d-delE/dn (rad/g)	-.029	-.184	-.012	-.108
	c-h	.0025	-.0617	.0116	-.0079
	S.M.(FREE)	.554	.372	.372	.197
	dF/dn (lbs/g)	-795.46	-974.41	-397.32	-517.95
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	90.42	80.00	80.00
	Passes MIL-F-8785C	no	no	no	no
	dF/dV (lbs/knot)	2.531	2.493	2.101	2.023
	F-S (lbs)	93.01	-534.96	423.46	-68.36

A B C D E F G H

5/21/1987

100 Pax Baseline Stick Force Calculations

	F.C. 1	F.C. 2	F.C. 3	F.C. 4
	Fwd c.g. Cruise	Fwd c.g. Vmc	Aft c.g. Cruise	Aft c.g. Vmc
h (ft)	30000	0	30000	0
density (slugs/ft3)	8.893e-4	2.377e-3	8.893e-4	2.377e-3
V (fps)	696.3	207.5	696.3	207.5
q-bar (psf)	215.58	51.17	215.58	51.17
X-bar-AC	.991	.982	.991	.982
X-bar-cg	.659	.659	.802	.802
Geometries, Inertias				
S (ft2)	1182	1182	1182	1182
b (ft)	132.50	132.50	132.50	132.50
c-bar (ft)	8.97	8.97	8.97	8.97
W (lb)	85044	85044	50666	50666
Ixx (slug-ft2)	1646875	1646875	888448	888448
Iyy (slug-ft2)	769820	769820	653359	653359
Izz (slug-ft2)	2326135	2326135	1455491	1455491
Steady State Coefficients				
CL	.334	1.406	.199	.838
CD	.017	.254	.016	.253
Longitudinal Derivatives				
C-L-a-A (rad-1)	6.53	6.60	6.53	6.60
C-m-dE (rad-1)	-3.97	-3.97	-3.84	-3.84
C-L-o	.170	.170	.170	.170
C-m-o	.100	.109	.100	.109
C-L-dE (rad-1)	.927	.928	.927	.928
C-L-i-H (rad-1)	1.716	1.718	1.716	1.718
C-m-i-H (rad-1)	-7.350	-7.358	-7.105	-7.113
C-m-alpha (rad-1)	-2.167	-2.131	-1.233	-1.188
C-m-q (rad-1)	-70.038	-70.124	-65.306	-65.385
	FC 1	FC 2	FC 3	FC 4
Lateral-Directional Derivatives				
C-n-Beta (rad-1)	.071	.096	.071	.096
C-l-p	-.792	-.632	-.792	-.632
C-l-dA (rad-1)	.608	.443	.608	.443
C-n-dR (rad-1)	.069	.077	.069	.077

Longitudinal Stick Force Calculations

>>	Eta-H	1.00	1.00	1.00	1.00
>>	Gearing Ratio (rad/ft)	.72	.72	.72	.72
>>	S-Elev. (ft2)	143.50	143.50	143.50	143.50
>>	C-Elev. (ft)	1.640	1.640	1.640	1.640
>>	C-h-dE (rad-1)	-.598	-.422	-.598	-.422
>>	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
>>	S-tab (ft2)	7.000	7.000	7.000	7.000
>>	C-tab (ft)	.570	.570	.570	.570
>>	C-h-alpha (rad-1)	-.346	-.241	-.346	-.241
>>	l-H (ft)	38.42	38.42	37.14	37.14
>>	Tau-E	.54	.54	.54	.54
>>	i-H (deg)	.00	.00	.00	.00
	dE/da	.214	.214	.214	.214
>>	n/alpha (g/rad)	23.32	5.53	37.17	8.82
	n-Limit	2.50	2.50	2.50	2.50
>>	R (d-tab / d-elev.)	.00	.00	.00	.00
	C-h-dE (tab + elev.)	-.5980	-.4220	-.5980	-.4220
	alpha-o-trim (rad)	-.032	-.032	-.031	-.031
	delta-o-trim (rad)	.043	.045	.036	.038
	d-alpha/dCL	.166	.164	.160	.159
	d-dE/dCL	-.091	-.088	-.052	-.049
	alpha-trim (rad)	.023	.199	.001	.102
	del-E-trim (rad)	.012	-.079	.026	-.003
>>	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	8.68e-5	1.1916e-3	2.94e-5	3.958e-4
	d-delE/dn (rad/g)	-.042	-.252	-.021	-.160
	c-h	-.0155	-.0145	-.0157	-.0232
	S.M.(FREE)	.056	.053	-.078	-.081
	dF/dn (lbs/g)	173.38	202.70	-19.76	65.22
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	90.42	80.00	80.00
	Passes MIL-F-8785C	no	no	no	yes
	dF/dV (lbs/knot)	-1.764	-1.066	-1.375	-.848
	F-S (lbs)	-566.97	-125.68	-573.52	-201.21

A	B C D	E	F	G	H
	Longitudinal Stick Force Calculations				

>>	Eta-H	1.00	1.00	1.00	1.00
>>	Gearing Ratio (rad/ft)	.72	.72	.72	.72
>>	S-Elev. (ft2)	143.50	143.50	143.50	143.50
>>	C-Elev. (ft)	1.640	1.640	1.640	1.640
>>	C-h-dE (rad-1)	-.598	-.422	-.598	-.422
>>	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
>>	S-tab (ft2)	7.000	7.000	7.000	7.000
>>	C-tab (ft)	.570	.570	.570	.570
>>	C-h-alpha (rad-1)	-.346	-.241	-.346	-.241
>>	l-H (ft)	38.42	38.42	37.14	37.14
>>	Tau-E	.54	.54	.54	.54
>>	i-H (deg)	.00	.00	.00	.00
	dE/da	.214	.214	.214	.214
>>	n/alpha (g/rad)	23.32	5.53	37.17	8.82
	n-Limit	2.50	2.50	2.50	2.50
>>	R (d-tab / d-elev.)	1.00	1.00	1.00	1.00
	C-h-dE (tab + elev.)	-1.6200	-1.4550	-1.6200	-1.4550
	alpha-o-trim (rad)	-.032	-.032	-.031	-.031
	delta-o-trim (rad)	.043	.045	.036	.038
	d-alpha/dCL	.166	.164	.160	.159
	d-dE/dCL	-.091	-.088	-.052	-.049
	alpha-trim (rad)	.023	.199	.001	.102
	del-E-trim (rad)	.012	-.079	.026	-.003
>>	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	8.68e-5	1.1916e-3	2.94e-5	3.958e-4
	d-delE/dn (rad/g)	-.042	-.252	-.021	-.160
	c-h	-.0283	.0671	-.0421	-.0200
	S.M.(FREE)	.230	.245	.090	.104
	------------------------------------	----------	----------	----------	----------
	dF/dn (lbs/g)	1392.01	1702.89	516.41	877.54
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	90.42	80.00	80.00
	Passes MIL-F-8785C	no	no	no	no
	------------------------------------	----------	----------	----------	----------
	dF/dV (lbs/knot)	-6.344	-4.918	-5.242	-4.129
	F-S (lbs)	-1032.86	582.08	-1537.50	-173.79

Longitudinal Stick Force Calculations

A	B C D	E	F	G	H
>>	Eta-H	1.00	1.00	1.00	1.00
>>	Gearing Ratio (rad/ft)	.72	.72	.72	.72
>>	S-Elev. (ft2)	143.50	143.50	143.50	143.50
>>	C-Elev. (ft)	1.640	1.640	1.640	1.640
>>	C-h-dE (rad-1)	-.598	-.422	-.598	-.422
>>	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
>>	S-tab (ft2)	7.000	7.000	7.000	7.000
>>	C-tab (ft)	.570	.570	.570	.570
>>	C-h-alpha (rad-1)	-.346	-.241	-.346	-.241
>>	l-H (ft)	38.42	38.42	37.14	37.14
>>	Tau-E	.54	.54	.54	.54
>>	i-H (deg)	.00	.00	.00	.00
	dE/da	.214	.214	.214	.214
>>	n/alpha (g/rad)	23.32	5.53	37.17	8.82
	n-Limit	2.50	2.50	2.50	2.50
>>	R (d-tab / d-elev.)	.50	.50	.50	.50
	C-h-dE (tab + elev.)	-1.1090	-.9385	-1.1090	-.9385
	alpha-o-trim (rad)	-.032	-.032	-.031	-.031
	delta-o-trim (rad)	.043	.045	.036	.038
	d-alpha/dCL	.166	.164	.160	.159
	d-dE/dCL	-.091	-.088	-.052	-.049
	alpha-trim (rad)	.023	.199	.001	.102
	del-E-trim (rad)	.012	-.079	.026	-.003
>>	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	8.68e-5	1.1916e-3	2.94e-5	3.958e-4
	d-delE/dn (rad/g)	-.042	-.252	-.021	-.160
	c-h	-.0219	.0263	-.0289	-.0216
	S.M.(FREE)	.183	.201	.045	.062
	dF/dn (lbs/g)	782.70	952.79	248.33	471.38
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	90.42	80.00	80.00
	Passes MIL-F-8785C	no	no	no	no
	dF/dV (lbs/knot)	-4.054	-2.992	-3.308	-2.488
	F-S (lbs)	-799.91	228.20	-1055.51	-187.50

A	B	E	F	G	H
	Longitudinal Stick Force Calculations				
>>	Eta-H	1.00	1.00	1.00	1.00
>>	Gearing Ratio (rad/ft)	.72	.72	.72	.72
>>	S-Elev. (ft2)	143.50	143.50	143.50	143.50
>>	C-Elev. (ft)	1.640	1.640	1.640	1.640
>>	C-h-dE (rad-1)	-.598	-.422	-.598	-.422
>>	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
>>	S-tab (ft2)	7.000	7.000	7.000	7.000
>>	C-tab (ft)	.570	.570	.570	.570
>>	C-h-alpha (rad-1)	-.346	-.241	-.346	-.241
>>	l-H (ft)	38.42	38.42	37.14	37.14
>>	Tau-E	.54	.54	.54	.54
>>	i-H (deg)	.00	.00	.00	.00
	dE/da	.214	.214	.214	.214
>>	n/alpha (g/rad)	23.32	5.53	37.17	8.82
	n-Limit	2.50	2.50	2.50	2.50
>>	R (d-tab / d-elev.)	-.50	-.50	-.50	-.50
	C-h-dE (tab + elev.)	-.0870	.0945	-.0870	.0945
	alpha-o-trim (rad)	-.032	-.032	-.031	-.031
	delta-o-trim (rad)	.043	.045	.036	.038
	d-alpha/dCL	.166	.164	.160	.159
	d-dE/dCL	-.091	-.088	-.052	-.049
	alpha-trim (rad)	.023	.199	.001	.102
	del-E-trim (rad)	.012	-.079	.026	-.003
>>	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	8.68e-5	1.1916e-3	2.94e-5	3.958e-4
	d-delE/dn (rad/g)	-.042	-.252	-.021	-.160
	c-h	-.0091	-.0553	-.0025	-.0248
	S.M. (FREE)	-1.567	1.531	-1.647	1.347
	dF/dn (lbs/g)	-435.94	-547.40	-287.84	-340.94
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	90.42	80.00	80.00
	Passes MIL-F-8785C	no	no	no	no
	dF/dV (lbs/knot)	.525	.860	.559	.793
	F-S (lbs)	-334.02	-479.56	-91.53	-214.93

A	B C D	E	F	G	H
	Longitudinal Stick Force Calculations				

))	Eta-H	1.00	1.00	1.00	1.00
))	Gearing Ratio (rad/ft)	.72	.72	.72	.72
))	S-Elev. (ft2)	143.50	143.50	143.50	143.50
))	C-Elev. (ft)	1.640	1.640	1.640	1.640
))	C-h-dE (rad-1)	-.598	-.422	-.598	-.422
))	C-h-d-tab (rad-1)	-1.022	-1.033	-1.022	-1.033
))	S-tab (ft2)	7.000	7.000	7.000	7.000
))	C-tab (ft)	.570	.570	.570	.570
))	C-h-alpha (rad-1)	-.346	-.241	-.346	-.241
))	1-H (ft)	38.42	38.42	37.14	37.14
))	Tau-E	.54	.54	.54	.54
))	i-H (deg)	.00	.00	.00	.00
	dE/da	.214	.214	.214	.214
))	n/alpha (g/rad)	23.32	5.53	37.17	8.82
	n-Limit	2.50	2.50	2.50	2.50
))	R (d-tab / d-elev.)	-1.00	-1.00	-1.00	-1.00
	C-h-dE (tab + elev.)	.4240	.6110	.4240	.6110
	alpha-o-trim (rad)	-.032	-.032	-.031	-.031
	delta-o-trim (rad)	.043	.045	.036	.038
	d-alpha/dCL	.166	.164	.160	.159
	d-dE/dCL	-.091	-.088	-.052	-.049
	alpha-trim (rad)	.023	.199	.001	.102
	del-E-trim (rad)	.012	-.079	.026	-.003
))	Load Factor (g's)	1.00	1.00	1.00	1.00
	d-delE/dV (rad/fps)	8.68e-5	1.1916e-3	2.94e-5	3.958e-4
	d-delE/dn (rad/g)	-.042	-.252	-.021	-.160
	c-h	-.0028	-.0961	.0107	-.0264
	S.M.(FREE)	.722	.510	.566	.361
	dF/dn (lbs/g)	-1045.26	-1297.49	-555.92	-747.10
	dF/dn MIN	23.33	23.33	23.33	23.33
	dF/dn MAX	80.00	90.42	80.00	80.00
	Passes MIL-F-8785C	no	no	no	no
	dF/dV (lbs/knot)	2.815	2.786	2.493	2.433
	F-S (lbs)	-101.08	-833.44	390.46	-228.64

$\tan \phi'/2 = \tan \phi''/2 = \tan \phi_{TE}/2 = .231$

$t/c_{\text{HOR. TAIL}} = .11$ $\quad C_E/C = .35$

$t/c_{\text{VER TAIL}} = .11$ $\quad C_R/C = .35$

$t/c_{\text{AIL}} = .13$ $\quad C_A/C = .3$

	H-T	V-T	AIL
$C_{h'_\alpha}/C_{h_{\alpha\,\text{THEORY}}}$	.9	.9	.9
$C_{h_{\alpha\,\text{THEORY}}}$	-.57	-.57	-.54
$C_{l_\alpha}/C_{l_{\alpha\,\text{THEORY}}}$	.955	.955	.955
C'_{h_α}	-.513	-.513	-.486
C''_{h_α}	-.445	-.445	-.429
t_c	.08	.08	.06
C_f	.27	.27	.22
C_b	.08	.08	.08
BAL. RATIO	.26	.26	.39
$C_{h_{\alpha\,\text{BAL}}}/C''_{h_\alpha}$	.68	.68	.30
$C_{h_{\alpha\,\text{BALANCE}}}$	-.303	-.303	-.129
C_{h_α} ...	-.424	-.424	-.181

VMC $M = .19$ (row $C_{h_{\alpha\,\text{BALANCE}}}$)

CRUISE $M = .7$ (row C_{h_α})

	H-T	V-T	A/C
$C_{h_\delta}' / C_{h_{\delta_{THEORY}}}$	.95	.95	.95
$C_{h_{\delta_{THEORY}}}$	-.90	-.90	-.85
C_{h_δ}'	-.855	-.855	-.808
$C_{\ell_\delta} / C_{\ell_{\delta_{THEORY}}}$	.92	.92	.92
$C_{\ell_{\delta_{THEORY}}}$	4.8	4.8	4.5
C_{h_δ}''	-.778	-.778	-.736
$\dfrac{C_{h_{\delta_{BALANCE}}}}{C_{h_\delta}''}$	.6	.6	.2
$C_{h_{\delta_{BALANCE}}}$	-.467	-.467	-.147
$C_{h_{\delta_{BALANCE}}}$	-.654	-.654	-.206

M = .19 (for first $C_{h_{\delta_{BALANCE}}}$ row)

M = .7 (for second $C_{h_{\delta_{BALANCE}}}$ row)

SECTION HINGE MOMENT SUMMARY

	H-T	V-T	AIL	
C_{h_α}	-.30	-.30	-.13	M = .19
C_{h_α}	-.42	-.42	-.18	M = .7
C_{h_δ}	-.47	-.47	-.15	M = .19
C_{h_δ}	-.65	-.65	-.21	M = .7

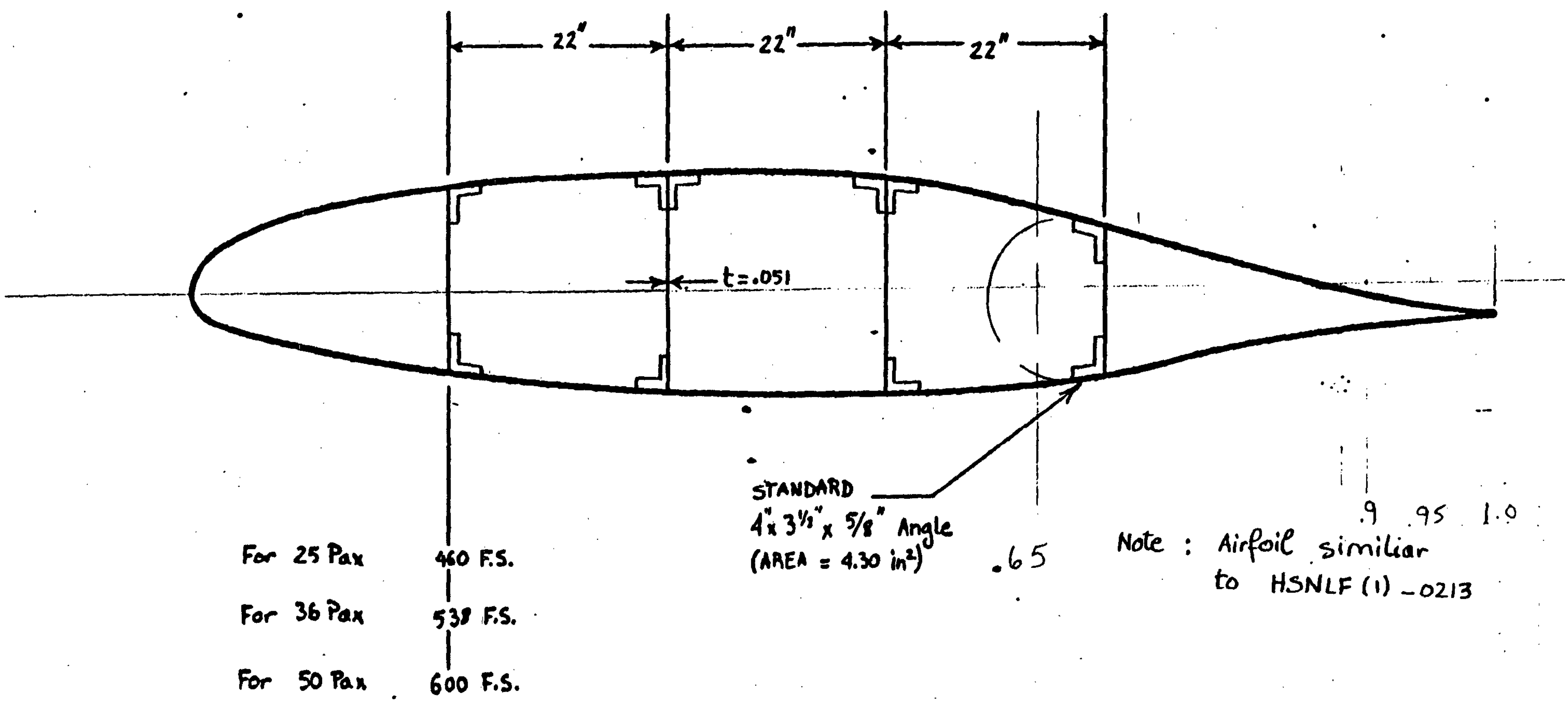

Figure 3.1 - Wing Cross Section

$$C_{h_\alpha} = \frac{A \cos \Lambda_{c/4}}{A + 2\cos \Lambda_{c/4}} \; C_{h_{\alpha\,BAL\,(SECTION)}} + \Delta C_{h_\alpha}$$

	H-T	V-T	AIL	T-D H-T	T-B AIL	
A	5.88	1.4	12	13.6	14.54	
$\Lambda_{c/4}$	20.8°	40°	13°	4.3°	10°	
K_α	1.0	1.0	3.02	1.0	3.44	
$\Delta C_{h_\alpha}/I$	.007	.015	.004	.004	.004	
B_2	.98	.98	.93	.98	.93	
ΔC_{h_α}	.038	.068	.066	.023	.076	
$C_{h_{\alpha\,BAL}}$	-.303	-.303	-.129	-.303	-.129	(VMC)
$C_{h_{\alpha\,BAL}}$	-.424	-.424	-.181	-.424	-.181	(CRUISE)
$\frac{A \cos \Lambda_{c/4}}{A + 2\cos \Lambda_{c/4}}$	.709	.366	.838	.870	.869	

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MODEL	25	36	50	75	100	
$C_{h_{\alpha_E}}$	-.177	-.177	-.177	-.241	-.241	(VMC)
$C_{h_{\alpha_E}}$	-.263	-.263	-.263	-.346	-.346	(CR)
$C_{h_{\alpha_R}}$	-.043	-.043	-.043	-.086	-.086	(VMC)
$C_{h_{\alpha_R}}$	-.087	-.087	-.087	-.174	-.174	(CR)
$C_{h_{\alpha_A}}$	-.042	-.042	-.042	-.036	-.036	(VMC)
$C_{h_{\alpha_A}}$	-.086	-.086	-.086	-.081	-.081	(CR)

$$\alpha_\delta = -\frac{(C_{\ell_\delta})_\alpha}{(C_{\ell_\alpha})_\delta}$$

$c_E/c = .35$ $\qquad\qquad$ $c_b/c_E = .296 \approx .3$

Fig. 6.1.1.1-42 $\quad C_{\ell_\delta} = .077 \ \text{deg}^{-1} = 4.412 \ \text{rad}^{-1}$

$C_{\ell_\alpha} = 6.0 \ \text{rad}^{-1}$

$\alpha_\delta = -.735$

$$\Delta C_{h_\delta} = \underbrace{\frac{\Delta C_{h_\delta}}{C_{\ell_\delta} B_2 K_\delta \cos\Lambda_{c/4} \cos\Lambda_{HL}}}_{I} \overbrace{\left(C_{\ell_\delta} B_2 K_\delta \cos\Lambda_{c/4} \cos\Lambda_{H.L.}\right)}^{I}$$

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax	
A_H	5.883	5.883	5.883	13.60	13.60	
Fig 6.1.6.2-15 $\frac{\Delta C_{h_\delta}}{(\ I\ )}$	.011	.011	.011	.004	.004	

Fig 6.1.6.1-19(c) $\quad B_2 = .93$

$$K_\delta = \frac{(K_\delta)_{\eta_i}(1-\eta_i) - (K_\delta)_{\eta_o}(1-\eta_o)}{\eta_o - \eta_i}$$

$\eta_i \doteq 0 \quad , \quad \eta_o = 1$

Fig. 6.1.6.2-15(b) $\quad (K_\delta)_{\eta_i} = 1.0 \quad , \quad (K_\delta)_{\eta_o} = 4.4$

$K_{\delta_E} = 1.0$

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax	
$\Lambda_{c/4_{H.T.}}$	.364	.364	.364	.076	.076	(rad
$(\Lambda_{H.L})_{H.T}$	.349	.349	.349	.065	.065	(rad
I	3.603	3.603	3.603	4.083	4.083	(rad
	.063	.063	.063	.071	.071	(de
ΔC_{h_δ}	.000693	.000693	.000693	.000284	.000284	(deg
	.0396	.0396	.0396	.0163	.0163	(rad

$$C_{h_{\delta_E}} = \cos\Lambda_{c/4} \cos\Lambda_{H.L}\left[(C_{h_\delta})_{bal} + \alpha_\delta (C_{h_\alpha})_{bal} \frac{2\cos\Lambda_{c/4}}{A + 2\cos\Lambda_{c/4}}\right] + \Delta C_{h_\delta}$$

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax	
$C_{h_{\delta_{E\,Vmc}}}$	−.323	−.323	−.823	−.422	−.422	(rad
$C_{h_{\delta_{E\,cruise}}}$	−.469	−.469	−.469	−.598	−.598	(rad

$c_R/c = .35$ $c_b/c_R \approx .3$

Fig. 6.1.1.1-42 $C_{l_\delta} = .077\ deg^{-1} = 4.412\ rad^{-1}$

$C_{l_\alpha} = 6.0\ rad^{-1}$

$\alpha_\delta = -.735$

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax	
$A_{V.T.}$	1.4	1.4	1.4	1.4	1.4	
Fig 6.1.6.2-15 $\frac{\Delta C_{h_\delta}}{(I)}$	.025	.025	.025	.025	.025	
Fig 6.1.6.1-19(c) $B_2 = .98$						
$K_{\delta_R} = 1.0$						
$\Lambda_{c/4_{V.T}} = .70$ rad.						
$\Lambda_{HL_{H.T}} = .436$ rad						
I	3.059	3.059	3.059	3.059	3.059	(rad^{-1})
ΔC_{h_δ}	.0765	.0765	.0765	.0765	.0765	(rad^{-1})
$C_{h_{\delta_R}\ V_{mc}}$	−.167	−.167	−.167	−.167	−.167	(rad^{-1})
$C_{h_{\delta_R}\ cruise}$	−.250	−.250	−.250	−.250	−.250	(rad^{-1})

$c_A/c = .30$ $c_b/c_A \approx .3$

Fig. 6.1.1.1-42 $C_{\ell_\delta} = .072 \text{ deg}^{-1} = 4.125 \text{ rad}^{-1}$

$C_{\ell_\alpha} = 6.0 \text{ rad}^{-1}$

$\alpha_\delta = -.686$

		25 Pax	36 Pax	50 Pax	75 Pax	100 Pax	
	A_W	12.0	12.0	12.0	14.843	14.843	
Fig 6.1.6.2-15	$\frac{\Delta C_{h_\delta}}{(I)}$	.005	.005	.005	0.003	.003	
Fig 6.1.6.1-19(c)	$B_2 = .93$						
	η_i	.850	.850	.850	.906	.906	
	η_o	.968	.968	.968	.981	.981	
Fig 6.1.6.2-15(b)	$(K_\delta)_{\eta_i}$	3.25	3.25	3.25	3.6	3.6	
	$(K_\delta)_{\eta_o}$	4.1	4.1	4.1	4.25	4.25	
	K_{δ_A}	3.02	3.02	3.02	3.44	3.44	
	$\Lambda_{c/4}$	.228	.228	.228	.177	.177	
	Λ_{HL}	.175	.175	.175	.128	.128	
	I	11.11	11.11	11.11	12.88	12.88	(rad⁻
	ΔC_{h_δ}	.056	.056	.056	.039	.039	(rad⁻
	$C_{h_{\delta_{AV_{MC}}}}$	−.073	−.073	−.073	−.094	−.094	(rad⁻
	$C_{h_{\delta_{A\,cruise}}}$	−.125	−.125	−.125	−.148	−.148	(rad⁻

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REFERENCE DATCOM SECTION 6.1.3.3

$c_f/c = .35$

$$\left(\frac{\partial C_{h_f}}{\partial \delta_t}\right)_{C_\ell,\,\delta_f} = A = -.015, \quad c_t/c_f = .35$$

$$\left(\frac{\partial C_{h_f}}{\partial \delta_t}\right)_{\delta_t,\,\delta_f} = B = -.067$$

$$\left(\frac{\partial C_\ell}{\partial \alpha}\right)_{\delta_t,\,\delta_f} = C = .105 = C_{\ell_\alpha}$$

$$\left(\frac{\partial \alpha}{\partial \delta_t}\right)_{C_\ell,\,\delta_f} = D = -.730$$

$$C_{h_{\delta_t}} = \left(\frac{\partial C_{h_f}}{\partial \delta_t}\right)_{\alpha,\,\delta_f}$$

$$C_{h_{\delta_t}} = A - BCD$$

$$C_{h_{\delta_t}} = -.020 \text{ DEG}^{-1}$$

$$\boxed{C_{h_{\delta_t}} = -1.154 \text{ RAD}^{-1}}$$

SECTIONAL C_{h_α} FOR TRIM TAB

$C_{h_\alpha}'' = -.445$ RAD^{-1} (NO BALANCE EFFECTS)

AT $M = .7$

$C_{h_\alpha}'' = -.623$ RAD^{-1}

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$$C_{h_{\delta_t}} = (\cos\Lambda_{c/4} \cos\Lambda_{H.L})(H.M) + \Delta C_{h_\delta}$$

$$H.M = C_{h_{\delta_t}} + \alpha_\delta C_{h_\alpha} \frac{2\cos\Lambda_{c/4}}{A + 2\cos\Lambda_{c/4}}$$

	H.T	V.T
$\Delta C_{h_\delta}/x$	.01	.03
B_2	1.1	1.1
K_δ	.75	.75
$\cos\Lambda_{c/4} \cos\Lambda_{HL}$	.83	.60
C_{l_δ}	4.4	4.4
α_δ	.54	.54
ΔC_{h_δ}	.003	.014
$\Lambda_{c/4}$	.364	.70
A	5.88	1.4

$\eta_i = .4$
$\eta_o = .8$

$C_{n_{\delta_t}}$ BASED ON S_t C_t

	H.T	V.T
VMC	-1.003	$-.754$
CR	-1.022	$-.784$

$\eta_i = .4$

$\eta_o = .8$

$c_t/c_e = .35$

S_t

c_t

Appendix G

Component Drag Calculations

Purpose: This appendix contains drag calculations following methods in Reference 13.

$$C_{D_{wing}} = C_{D_{0w}} + C_{D_{L_w}} \quad \text{(NLF Considerations)}$$

$$* \; C_{D_{0w}} = (R_{wf})(R_{LS})\left[1 + L'\left(\frac{t}{c}\right) + 100\left(\frac{t}{c}\right)^4\right]\left[(C_{f_{w_{lam}}} - C_{f_{w_{tur}}}) S_{wet_{w_{lam}}} + C_{f_w} S_{wet_w}\right]\frac{1}{S}$$

$M_{cruise} = 0.7$
$M_{app} = 0.15$

cruise : $\rho = .8873 \times 10^{-3}$ slug/ft³ , $\mu = 3.106 \times 10^{-7}$
approach: $\rho = 2.377 \times 10^{-3}$ " , $\mu = 3.737 \times 10^{-7}$

		25 Pax	36 Pax	50 Pax	75 Pax	100 Pax	
	l_f (corr)	71.33	79.0	96.33	79.0	96.33	(ft
	$R_{N_{fus\,cruise}}$	138×10^6	156×10^6	189×10^6	156×10^6	189×10^6	
	$R_{N_{fus\,app}}$	7.6×10^7	8.4×10^7	1.0×10^8	8.4×10^7	1.0×10^8	
Fig 4.1	$R_{wf_{cruise}}$	1.015	1.015	1.015	1.015	1.015	
Fig 4.1	$R_{wf_{app}}$	.932	.930	.928	.930	.928	

$\cos \Lambda_{(t/c)_{max}} = .981$

Fig 4.2 $\quad R_{L.S._{cruise}} = 1.2$

Fig 4.2 $\quad R_{L.S._{app}} = 1.07$

$\bar{c}_{w_e} = 11$ ft

$R_{N_{w_{cruise}}} = 2.2 \times 10^7$, $R_{N_{w_{app}}} = 1.2 \times 10^7$

Fig 4.3 $\quad C_{f_{w_{cruise}}} = .00255$, $C_{f_{w_{app}}} = .00294$

$L' = 1.2$

$t/c = .13$

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax	
S_{wet_w}	1164	1164	1164	2224	2224	(ft²
S	592	592	592	1182	1182	(ft²

$c_{w_{lam}} = 5.5$ ft (50%)

$R_{N_{w_{lam\,cruise}}} = 1.1 \times 10^7$, $R_{N_{w_{lam\,app}}} = .6 \times 10^7$

$C_{f_{w_{lam\,cruise}}} = .0004$, $C_{f_{w_{lam\,app}}} = .0005$

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax	
$S_{wet_{wlam}}$	582	582	582	1112	1112	$(ft^2$
→ $C_{D_{0W_{cruise}}}$	.0042	.0042	.0042	.0040	.0040	
→ $C_{D_{0W\,app}}$	.0040	.0040	.0040	.0038	.0038	

$$* \quad C_{D_{L_W}} = (C_{L_W})^2/\pi A e + 2\pi C_{L_W} \varepsilon_t v + 4\pi^2 (\varepsilon_t)^2 w$$

$$C_{L_W} = 1.05\, C_L = 1.05 \left(\frac{W}{\bar{q} S}\right)$$

W	28,506	35,954	43,141	71,419	85,044	(lbs
S	592	592	592	1182	1182	$(ft^2$
$\bar{q}_{cruise}$	215.6	215.6	215.6	215.6	215.6	
$\bar{q}_{app}$	32.9	39.4	39.8	40.24	40.24	
$C_{L_{W cruise}}$	.235	.296	.355	.294	.350	
$C_{L_{W app}}$	1.47	1.54	1.83	1.50	1.79	

$$e = 1.1 \left(\frac{C_{L\alpha_W}}{A}\right) \Big/ \left[R\left(\frac{C_{L\alpha_W}}{A}\right) + (1-R)\pi\right]$$

$C_{L\alpha_{W_{cruise}}}$	4.7089	4.7089	4.7089	4.9097	4.9097	(rd
$C_{L\alpha_{W app}}$	4.7794	4.7794	4.7794	4.9673	4.9673	(rd

$l_{er} = .2$ ft ; $\lambda = .4$

Fig 4.7 $\quad R_{l_{ler_{cruise}}} = \rho u_1 \frac{l_{ler}}{\mu} = .399 \times 10^6$, $R_{l_{ler\,app}} = .100 \times 10^6$

Λ_{LE}	.262	.262	.262	.201	.201
A	12.0	12.0	12.0	14.84	14.84
Fig 4.7(b) R	.960	.960	.960	.965	.965

		25 Pax	36 Pax	50 Pax	75 Pax	100 Pax
	A	12.0	12.0	12.0	14.84	14.84
	e_{cruise}	.859	.859	.859	.848	.848
	$e_{app.}$	.862	.862	.862	.894	.894
	$\pi A e_{cruise}$	32.38	32.38	32.38	39.53	39.53
	$\pi A e_{app.}$	32.50	32.50	32.50	41.68	41.68

It is assumed that the twist angle $\varepsilon_t = 1° = .017 rd$

Fig 4.9(a)	v	.0009	.0009	.0009	.0008	.0008
Fig 4.10(a)	w	.0003	.0003	.0003	.0003	.0003
	$C_{D_{L_{W_{cruise}}}}$	.0017	.0027	.0039	.0022	.0031
	$C_{D_{L_{W_{app}}}}$	.0666	.0730	.1032	.0541	.0770

then

$C_{D_{wing_{cruise}}}$	.0059	.0069	.0081	.0062	.0071
$C_{D_{wing_{app.}}}$	.0706	.0770	.1072	.0579	.0808

$$C_{D_{fus}} = C_{D_{o\,fus}} + C_{D_{L\,fus}}$$

$$* \quad C_{D_{o\,fus}} = \frac{R_{wf}}{S}\left[1 + \frac{60}{(\ell_f/d_f)^3} + .0025\left(\frac{\ell_f}{d_f}\right)\right]\left[\left(C_{f_{fus_{lam}}} - C_{f_{fus_{tur}}}\right) S_{wet_{fus_{lam}}} + C_{f_{fus}} S_{wet_{fus}}\right]$$
$$+ \; C_{D_{b\,fus}}$$

		25 Pax	36 Pax	50 Pax	75 Pax	100 Pax
	ℓ_f	69.4	78.1	94.6	78.1	94.6 (ft)
	$R_{N_{fus}}$	1.38×10^8	1.557×10^8	1.886×10^8	1.557×10^8	1.886×10^8
Fig 4.1	R_{wf}	1.015	1.015	1.015	1.015	1.015
Fig 4.3	$C_{f_{fus}}$	.00195	.0019	.00185	.0019	.00185

$d_f = 8.05$ ft

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax
$S_{wet_{fus}}$	450	503	651	2(503)	2(651) (ft²)

$$R_{N_{fus_{lam}}} = \rho U_1 \frac{\ell_{f_{lam}}}{\mu}$$

$$\ell_{f_{lam}} = 12.5 \text{ ft}$$

$$R_{N_{fus_{lam}}} = 2.49\times10^7$$

$$C_{f_{fus_{lam}}} = 1.33\left(\sqrt{R_{N_{fus_{lam}}}}\right)^{-1} = 0.00027$$

$S_{wet_{fus_{lam}}} = 101$ ft² (75 Pax: 2(101); 100 Pax: 2(101))

$C_{D_{b\,fus}} = 0$ because of the lack of base.

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax
→ $C_{D_{o\,fus}}$	0.00191	0.00148	0.00191	0.00148	0.00191

* $C_{D_{L_{fus}}} = 2\alpha^2 S_{b_{fus}}/S + \eta c_{d_c} \alpha^3 S_{plf_{fus}}/S$

$$\alpha = \left[\frac{W}{qS} - C_{L_o}\right]\frac{1}{C_{L_\alpha}}$$

$$C_{L_{o_{cruise}}} = C_{L_{o_{approach}}} = 0.17$$

		25 Pax	36 Pax	50 Pax	75 Pax	100 Pax	
	$C_{L_{\alpha_{cruise}}}$	5.479	5.479	5.422	6.424	6.249	
	$C_{L_{\alpha_{approach}}}$	5.565	5.565	5.507	6.496	6.311	
	α_{cruise}	.0097	.0204	.0309	.0172	.0262	
	$\alpha_{app.}$	.0096	.0201	.0305	.0170	.0259	
Fig 4.17	$S_{b_{fus}} = 0.5\ ft^2$						
Fig 4.17	$d_f = 96.6'' = 8.05\ ft$						
	l_f	69.4	78.1	94.6	78.1	94.6	(ft)
Fig 4.19	η	.670	.685	.705	.685	.705	
Fig 4.20	c_{d_c}	1.2	1.2	1.2	1.2	1.2	
Fig 4.17	$S_{plf_{fus}}$	490	553	698	2(553)	2(698)	(ft²)
⟶	$C_{D_{L_{fus\,(cruise)}}}$	.0000	.0000	0.0001	.0000	.0001	
⟶	$C_{D_{L_{fus\,(app)}}}$	.0000	.0000	0.0001	.0000	.0001	
then	$C_{D_{fus}}$	.0019	.0015	.0020	.0015	.0020	

* Windshield drag is negligable and is accounted for in the fuselage drag. $\rightarrow$ $C_{D_{cw}} = 0$

$$C_{D_{H.T.}} = C_{D_{o_{H.T.}}} + C_{D_{L_{H.T.}}}$$

$$* \quad C_{D_{o_{H.T.}}} = (R_{LS})\left[1 + L'\left(\frac{t}{c}\right) + 100\left(\frac{t}{c}\right)^4\right]\left[\left(C_{f_{H.T_{lam}}} - C_{f_{H.T_{tur}}}\right) S_{wet_{H.T_{lam}}} + C_{f_{H.T}} S_{wet_{H.T}}\right]\frac{1}{S}$$

$M_{cruise} = .7$
$M_{app} = .15$

		25 Pax	36 Pax	50 Pax	75 Pax	100 Pax	
	$\Lambda_{HT\,(t/c)max}$	.314	.314	.314	.052	.052	(rd)
Fig 4.2	$R_{L.S\,cruise}$	1.2	1.2	1.2	1.21	1.21	
Fig 4.2	$R_{L.S\,app}$	1.07	1.07	1.07	1.08	1.08	

$R_{N_{HT}} = \rho U_1 \bar{c}_{H.T_e} / \mu$

Cruise $\rho = .8893 \times 10^{-3}\ \frac{slug}{ft^3}$; $\mu = 3.106 \times 10^{-7}\ \frac{lb\cdot s}{ft^2}$; $U_1 = 696.29$ ft/s

Approach $\rho = 2.377 \times 10^{-3}\ \frac{slug}{ft^3}$; $\mu = 3.737 \times 10^{-7}\ \frac{lb\cdot s}{ft^2}$; $U = 167.46$ ft/s

$\bar{c}_{H.T_{ap}} = 6.02$ ft

$R_{N_{H.T\,cruise}} = 1.20 \times 10^7$

$R_{N_{H.T\,app.}} = 6.41 \times 10^6$

Fig 4.3 $\quad C_{f_{cruise_{H.T}}} = .00280$

Fig 4.3 $\quad C_{f_{app_{H.T}}} = .00321$

Fig 4.4 $\quad L' = 1.2$

$t/c = .13$

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax	
$S_{wet_{H.T}}$	200	200	200	780	780	(ft²)
S	592	592	592	1182	1182	(ft²)

$C_{f_{H.T_{lam}}} = 1.33\left(\sqrt{R_{N_{H.T_{lam}}}}\right)^{-1}$

$R_{N_{H.T_{lam}}} = \rho U_1 \bar{c}_{H.T_{lam}} / \mu$

$\bar{c}_{H.T_{lam}} = 3.01$ ft (50%)

$$R_{N_{H.T.lam\,cruise}} = 6.0 \times 10^6$$

$$R_{N_{H.T.lam\,app.}} = 3.21 \times 10^6$$

$$C_{f_{H.T.lam\,cruise}} = 5.43 \times 10^{-4}$$

$$C_{f_{H.T.lam\,app.}} = 7.43 \times 10^{-4}$$

$$S_{wet_{H.T.lam}} = .5\,(S_{wet_{H.T}})$$

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax
$S_{wet_{H.T\,lam}}$	100	100	100	390	390 (ft^2)
→ $C_{D_{o_{H.T\,cruise}}}$	.00080	.00080	.00080	.00160	.00160
→ $C_{D_{o_{H.T\,App.}}}$	.00085	.00085	.00085	.00167	.00167

$$* \quad C_{D_{L_{H.T}}} = \left[\left(C_{L_h}\right)^2 / \pi A_h e_h\right] \frac{S_h}{S}$$

$$C_{L_h} = C_{L_{\alpha_h}} \alpha_h$$

$$C_{L_{\alpha_h\,cruise}} = 3.6488$$

$$C_{L_{\alpha_h\,app}} = 3.7568$$

$$\alpha_h = \alpha\left(1 - \frac{d\varepsilon}{d\alpha}\right)$$

$$1 - \frac{d\varepsilon}{d\alpha} = .764$$

$$e_h = .75$$

HORIZONTAL TAIL | LEIS FOLFI | R. HALLAL

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax	
α_{cruise}	.0097	.0204	.0309	.0172	.0262	(r
$\alpha_{app.}$	.0096	.0201	.0305	.0170	.0259	(r
$\alpha_{h_{cruise}}$	.0074	.0156	.0236	.0131	.0200	(r
$\alpha_{h_{app}}$	.0073	.0154	.0233	.0130	.0198	
$C_{L_{h_{cruise}}}$	.0270	.0569	.0861	.0478	.0729	
$C_{L_{h_{app}}}$	.0274	.0579	.0875	.0488	.0744	
A_h	5.0	5.0	5.0	12.78	12.78	
S_h	102	102	102	392	392	(f
S	592	592	592	1182	1182	
→ $C_{D_{L_{HT cruise}}}$	.00001	.00004	.00011	.00003	.00008	
→ $C_{D_{L_{HT app}}}$	.00001	.00005	.00011	.00003	.00008	
then $C_{D_{H.T.}}$	.0008	.0008	.0009	.0016	.0016	

$$C_{D_{V.T}} = C_{D_{o_{V.T}}} + C_{D_{L_{V.T}}}$$

But in this case $C_{D_{L_{V.T}}} = 0$

$$\therefore \; C_{D_{V.T}} = C_{D_{o_{V.T}}}$$

$$* \; C_{D_{o_{V.T}}} = (R_{LS})\left[1 + L'\left(\tfrac{t}{c}\right) + 100\left(\tfrac{t}{c}\right)^4\right]\left[\left(C_{f_{V.T_{lam}}} - C_{f_{V.T_{tur}}}\right) S_{wet_{V.T_{lam}}} + C_{f_{V.T}} S_{wet_{V.T}}\right] \frac{1}{S}$$

		25 Pax	36 Pax	50 Pax	75 Pax	100 Pax
	$\Lambda_{VT(c/4)max}$	.687	.687	.687	.687	.687
Fig. 4.2	$R_{L.S_{cruise}}$	1.24	1.24	1.24	1.24	1.24
Fig 4.2	$R_{L.S_{app}}$	1.02	1.02	1.02	1.02	1.02

$R_{N_{V.T}} = \rho U_1 \bar{c}_{V.T_e} / \mu$

$\bar{c}_{V.T_e} = 16.6$ ft

Fig 4.3 $\quad R_{N_{V.T\,cruise}} = 3.31 \times 10^7 \Rightarrow C_{f_{V.T\,cruise}} = .0024$

Fig 4.3 $\quad R_{N_{V.T\,app}} = 1.77 \times 10^7 \Rightarrow C_{f_{V.T\,app}} = .0027$

Fig 4.4 $\quad L' = 1.2$, $\quad t/c = .13$

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax
$S_{wet_{V.T}}$	340	340	340	680	680

$\bar{c}_{V.T_{lam}} = 8.3$ ft (50%)

$R_{N_{V.T_{lam}}} = \rho U_1 \bar{c}_{V.T_{lam}} / \mu \quad ; \quad C_{f_{lam}} = 1.33\left(\sqrt{R_{N_{lam}}}\right)^{-1}$

$R_{N_{V.T_{lam\,cruise}}} = 1.65 \times 10^7 \Rightarrow C_{f_{lam\,cruise}} = 3.27 \times 10^{-4}$

$R_{N_{V.T_{lam\,app}}} = 8.84 \times 10^6 \Rightarrow C_{f_{lam\,app}} = 4.47 \times 10^{-4}$

$S_{wet_{V.T_{lam}}} = .5\left(S_{wet_{V.T}}\right)$

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax
$S_{wet_{V.T_{lam}}}$	170	170	170	340	340

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax
→ $C_{D_{o\,V.T\,cruise}}$	.0012	.0012	.0012	.0012	.0012
→ $C_{D_{o\,V.T\,app}}$	.0011	.0011	.0011	.0011	.0011

But $C_{D_{o\,V.T}} = C_{D_{V.T}}$

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax
then $C_{D_{V.T}}$	.0012	.0012	.0012	.0012	.0012

$$C_{D_{n/p}} = C_{D_n} + C_{D_P} + C_{D_{n_{int}}} + \Delta C_{D_{wm_{prop}}}$$

$$* \quad C_{D_n} = (C_{D_n})_i = 2C_{D_{n_0}} \qquad (C_{D_{L_n}} \text{ is negligeable}, \simeq 0)$$

$$C_{D_{n_0}} = C_{f_n}\left[1 + \frac{60}{(\ell_n/d_n)^3} + .0025\left(\frac{\ell_n}{d_n}\right)\right] S_{wet_n}/S + C_{D_{b_n}}$$

		25 Pax	36 Pax	50 Pax	75 Pax	100 Pax	
	ℓ_n	17.5	17.5	17.5	22.9	22.9	(ft
	$R_{N_{n_{app.}}}$	1.86×10^7	1.86×10^7	1.86×10^7	2.44×10^7	2.44×10^7	
Fig 4.3	$C_{f_{n_{app.}}}$	.0027	.0027	.0027	.0026	.0026	
	d_n	3.333	3.333	3.333	4.333	4.333	
	S_{wet_n}	53.89	53.89	53.89	92.08	92.08	

$C_{D_{b_n}} = 0$ because there is no end.

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax
→ $C_{D_{n_0}}$	.0004	.0004	.0004	.0003	.0003
→ $C_{D_{n_{app}}}$	.0008	.0008	.0008	.0006	.0006

$$* \quad C_{D_{0_p}} = (R_{pf})(R_{LS})(C_{f_p})\left[1 + L'\left(\frac{t}{c}\right) + 100\left(\frac{t}{c}\right)^4\right] S_{wet_p}/S$$

		25 Pax	36 Pax	50 Pax	75 Pax	100 Pax	
	$\Lambda_{p_{(t/c)_{max}}}$	.281	.281	.281	.314	.314	(rd
	ℓ_f (corr.)	71.33	79.00	96.33	79.00	96.33	(ft
	$R_{N_{fus\,app}}$	7.6×10^7	8.4×10^7	1.0×10^8	8.4×10^7	1.0×10^8	
Fig 4.1	R_{pf}	.930	.930	.928	.930	.928	
Fig 4.2	$R_{L.S_{app}}$	1.07	1.07	1.07	1.07	1.07	
	$\bar{c}_{p_e}$	10.83	10.83	10.83	11.67	11.67	(ft)
	$R_{N_{p_{app.}}}$	1.2×10^7	1.2×10^7	1.2×10^7	1.24×10^7	1.24×10^7	

		[illegible]	50 Pax	50 Pax	75 Pax	100 Pax
Fig 4.5	$C_{f_{p\,eff}}$	.0029	.0029	.0029	.00287	.00287
Fig 4.4	$L' = 1.2$					
	$t/c = .12$					
	$2(S_{wet_e})$	448	448	448	663	663
	S	592	592	592	1182	1182
⟶	$C_{D_{0p}}$	.0025	.0025	.0025	.0019	.0019

$$C_{D_{L_p}} = 2\left[(C_{L_p})^2 / \pi A_p e_p \right] \frac{S_p}{S}$$

$$C_{L_p} = C_{L_{\alpha_p}} \alpha_p$$

$C_{L_{\alpha p}}$	1.5320	1.5320	1.5320	1.9622	1.9622

$\alpha_p = \alpha\left(1 - \frac{d\varepsilon}{d\alpha}\right)$; $1 - \frac{d\varepsilon}{d\alpha} = 1.0$

	$\alpha_p = \alpha$	.0096	.0201	.0305	.0170	.0259
	C_{L_p}	.0147	.0308	.0467	.0334	.0508
	A_p	1.080	1.080	1.080	1.487	1.487
	$e_p = .5$					
	S_p	112	112	112	165.8	165.8
⟶	$C_{D_{L_p}}$	.0001	.0002	.0005	.0001	.0003

$$C_{D_p} = C_{D_{0p}} + C_{D_{Lp}}$$

⟶	C_{D_p}	.0026	.0026	.0030	.0020	.0022

* $C_{D_{n_{int}}}$ is negligeable because of the large distance between the nacelle and the fuselage.
Actually, that interference has been accounted for in the C_{D_n} calculations.

* $$\Delta C_{D_{wmprop}} = 2\left[33\left(\frac{1}{\bar{q}S}\right) SHP_{rated}\left(\frac{1}{U_1}\right)\right]$$ (2 engines)

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax	
S	592	592	592	1182	1182	(ft²)
SHP_{rated} (per engine)	5500	5500	5500	11000	11000	(HP)

$\bar{q}_{cruise} = 215.6$ $\frac{slug}{ft \cdot s^2}$

$U_1 = 696.29$ ft/s

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax
→ $\Delta C_{D_{wmp}}$	.0041	.0041	.0041	.0041	.0041

then,

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax
$C_{D_{np}}$	.0075	.0075	.0079	.0067	.0069

the calculations presented here are applied only at low speed (which is at approach M=.15)

$$C_{D_{gear}} = i\left[C_{D_{nose\ gear}} + C_{D_{main\ gear}}\right].$$

For landing gears with more than one wheel per bogey :

$$C_{D_{mgear}} = \Delta f_{gear} / S \quad \text{(main gear)}$$

$$C_{D_{ng}} = \left(C_{D_{ngear_{C_L=0}}} + P\, C_L\right)\frac{S_{gear}}{S} \quad \text{where } P = -.4\, C_{D_{ng_{C_L=0}}}$$

$a = 14\ ft$

$b_t = 1.9\ ft$

$D_t = 1.5\ ft$

$e = 4.2\ ft$

Fig. 4.58 $C_{D_{ng_{C_L=0}}} = 0.8 \Rightarrow P = -.32$

$C_L = \dfrac{W}{\bar{q} S}$

$S_{gear_{nose}} = b_t \times D_t = 2.85\ ft^2$

		25 Pax	36 Pax	50 Pax	75 Pax	100 Pax
	W	28,506	35,954	43,141	71,419	85,044
	S	592	592	592	1182	1182
	$\bar{q}_{app}$	32.8	39.4	39.8	40.24	40.24
	$C_{L_{app.}}$	1.47	1.54	1.83	1.50	1.79
Fig. 4.60	Δf_{gear}	24	25	27	N.A.	N.A.

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax
→ $C_{D_{n.gear}}$	.0016	.0015	.0010	.0030	.0020
→ $C_{D_{m\,gear}}$	.0405	.0422	.0456	.0844	.0912

then,

$C_{D_{gear}}$	.0421	.0437	.0466	.0874	.0932

Appendix H

Mission performance verification.

Purpose: Presentation of methods in Reference 10 detailing the calculations for mission performance. This appendix contains calculations for:

a) Take-off field length

b) Landing field length

c) FAR 25 climb requirements

The work was done using a spreadsheet so all five airplanes could be checked simultaneously.

AE 790 M. RUSSELL 4/9/87

Performance Validation for the Family of Commuter Airplanes

Take-off Distance Calculations

	Ground Distance	25	36	50	75	100
>>	W-TO = W-L (lbs)	28506	35954	43141	71419	85044
>>	Thrust-TO (lbs)	14283	17330	21461	34224	41727
>>	Friction Coeff.	.025	.025	.025	.025	.025
>>	Phi Angle (rad)	0	0	0	0	0
	T/W - T.O.	.501	.482	.497	.479	.491
	F-s (lbs)	13570	16431	20382	32439	39601
>>	Wing Area	592	592	592	1182	1182
>>	Density	.002377	.002377	.002377	.002377	.002377
	C-L-max-TO	.97	1.22	1.47	1.22	1.45
	V-s-TO (fps)	204.4	204.4	204.4	204.4	204.4
>>	V-LOF (fps)	224.8	224.8	224.8	224.8	224.8
	q-bar-LOF (psf)	60.1	60.1	60.1	60.1	60.1
	C-L-TO	.802	1.011	1.213	1.006	1.198
>>	C-D-TO	.144	.163	.211	.181	.220
	D-LOF (lbs)	5120.0	5809.6	7507.4	12827.5	15628.3
	L-LOF (lbs)	34492.3	43504.3	52200.6	86417.0	102903.2
	F-LOF (lbs)	9312.7	11709.1	14180.1	21771.4	26545.2
	F-m (lbs)	11308.3	13937.1	17094.2	26751.5	32639.0
	S-G (ft)	1979.9	2026.2	1982.2	2096.9	2046.5
	Rotation Distance					
	S-R (ft)	674.4	674.4	674.4	674.4	674.4
	Transition Distance					
	Delta C-L	.140	.156	.171	.155	.170
	Radius, R (ft)	8989	10192	11142	10165	11076
	Theta-CL (rad)	.321	.320	.323	.300	.307
	S-TR (ft)	670	714	746	713	744
	Climb Distance					
	h-TR (ft)	460.4	518.7	577.8	452.8	517.5
	S-CL (ft)	0	0	0	0	0

	S-T.O. (ft)	3325	3414	3403	3484	3465

Landing Distance Calculations

	C-L-max-L	1.35	1.71	2.05	1.70	2.02
	V-S-L (fps)	172.9	172.9	172.9	172.9	172.9
>>	V-A (fps)	224.8	224.8	224.8	224.8	224.8
	V-TD (fps)	198.9	198.9	198.9	198.9	198.9
	C-L-Approach	.80	1.01	1.21	1.01	1.20
	q-bar-A (psf)	60.06	60.06	60.06	60.06	60.06
>>	C-D-Approach	.181	.200	.248	.247	.286
	D-A (lbs)	6436	7111	8818	17535	20304
	Gamma (rad)	.052	.052	.052	.052	.052
	Thrust- A	4943.2	5228.8	6559.2	13795.8	15851.1
	S-A (ft)	955.0	955.0	955.0	955.0	955.0
	S-FR (ft)	596.6	596.6	596.6	596.6	596.6
>>	Braking Coeff.	.45	.45	.45	.45	.45
	F-S (lbs)	12828	16179	19413	32139	38270
	C-L-T(OGE)	.80	1.01	1.21	1.01	1.20
>>	wing ht., h (ft)	8.00	8.00	8.00	8.00	8.00
>>	span, b	84.30	84.30	84.30	84.30	84.30
>>	m.g.c. (ft)	7.45	7.45	7.45	7.45	7.45
>>	Aspect Ratio (wing)	12.00	12.00	12.00	12.00	12.00
>>	Oswald's e-landing	.750	.750	.750	.750	.750
>>	wing t/c	.130	.130	.130	.130	.130
>>	Lamda c/2 wing (rad)	.194	.194	.194	.194	.194
	2h/b	.190	.190	.190	.190	.190
	h/b	.095	.095	.095	.095	.095
	h/c-bar	1.07	1.07	1.07	1.07	1.07
>>	A/Aeff (Fig. 10.8)	.43	.43	.43	.43	.43
	Aeff	27.9	27.9	27.9	27.9	27.9
	sigma'	.499	.499	.499	.499	.499
	C-L-a(OGE)	5.24	5.24	5.24	5.24	5.24
	C-L-a(IGE)	5.75	5.75	5.75	5.75	5.75
	delta-alpha-o (deg)	.418	.418	.418	.418	.418
	C-L(IGE)	.84	1.07	1.29	1.06	1.27
	delta-C-D-i	-.011	-.018	-.026	-.018	-.025
	C-D-taxi	.170	.182	.222	.229	.261
	F-B (lbs)	7062	7878	9451	18328	20948
	k	.753	.713	.713	.765	.751
	F-m (lbs)	9660	11535	13840	24590	28744
	S-B (ft)	1814	1916	1916	1785	1819
	Land. Dist. S-L (ft)	3365	3467	3468	3337	3370

Climb Requirements

#	FAR Req.	Flap Set	Gear Set	V xVs	Thrust Set	Wt.
1	25.111 OEI initial	TO	up	1.2	TO	TO
2	25.121 OEI transition	TO	down	1.15	TO	TO
3	25.121 OEI 2nd segment	TO	up	1.2	TO	TO
4	25.121 OEI en route	clean	up	1.25	MC	TO
5	25.119 AEO landing	landing	down	1.3	TO	L
6	25.121 OEI landing	approach	down	1.1<V <1.5	TO	L

Actual Climb Gradients

Case 1 — Initial

	25	36	50	75	100
Weight (lbs)	28506	35954	43141	71419	85044
Thrust (lbs)	7142	8665	10731	17112	20864
Density (slug/ft3)	.002377	.002377	.002377	.002377	.002377
Wing Area (ft2)	592	592	592	1182	1182
Velocity (fps)	245	245	245	245	245
C-L	.674	.850	1.020	.845	1.007
>> C-D	.096	.110	.151	.086	.117
R.C. (fps)	26.5	27.2	24.6	33.8	31.7
Climb Grad. %	10.79	11.10	10.04	13.77	12.93
Req'd. Grad. %	1.20	1.20	1.20	1.20	1.20
Passed Reqmt.	yes	yes	yes	yes	yes

Case 2 — Transition

	25	36	50	75	100
Velocity (fps)	235	235	235	235	235
C-L	.734	.925	1.110	.920	1.096

>> C-D	.141	.158	.204	.177	.215
R.C. (fps)	13.78	16.44	15.32	11.18	11.66
Climb Grad. %	5.86	6.99	6.52	4.76	4.96
Req'd. Grad. %	0	0	0	0	0
Passed Reqmt.	yes	yes	yes	yes	yes

Case 3 — Second Segment

	25	36	50	75	100
Velocity (fps)	245	245	245	245	245
C-L	.674	.850	1.020	.845	1.007
>> C-D	.096	.110	.151	.086	.117
R.C. (fps)	26.46	27.23	24.62	33.77	31.70
Climb Grad. %	10.79	11.10	10.04	13.77	12.93
Req'd. Grad. %	2.400	2.400	2.400	2.400	2.400
Passed Reqmt.	yes	yes	yes	yes	yes

Case 4 — En Route

	25	36	50	75	100
Velocity (fps)	255	255	255	255	255
C-L	.621	.783	.940	.779	.928
>> C-D	.094	.101	.109	.101	.109
R.C. (fps)	25.33	28.62	33.83	28.16	32.76
Climb Grad. %	9.92	11.20	13.24	11.02	12.83
Req'd. Grad. %	2.40	2.4	2.4	2.4	2.4
Passed Reqmt.	yes	yes	yes	yes	yes

Case 5 — Landing

	25	36	50	75	100
Thrust	14283	17330	21461	34224	41727
Velocity (fps)	266	266	266	266	266
C-L	.574	.724	.869	.720	.858
C-D	.134	.156	.226	.177	.232
R.C. (fps)	70.93	70.79	63.00	61.90	58.47
Climb Grad. %	26.70	26.65	23.71	23.30	22.01
Req'd. Grad. %	3.20	3.20	3.20	3.20	3.20

Passed Reqmt.	yes	yes	yes	yes	yes

Case 6 — Landing Approach

	25	36	50	75	100
Thrust	7142	8665	10731	17112	20864
Velocity (fps)	307	307	307	307	307
C-L	.802	1.011	1.213	1.006	1.198
C-D	.144	.171	.248	.189	.249
R.C. (fps)	15.94	16.07	9.92	11.59	8.45
Climb Grad. %	5.20	5.24	3.24	3.78	2.76
Req'd. Grad. %	2.10	2.10	2.10	2.10	2.10
Passed Reqmt.	yes	yes	yes	yes	yes

Actual Climb Gradients for the Commuter Family

Climb Reqmt. #	25	36	50	75	100
1	10.79	11.10	10.04	13.77	12.93
2	5.86	6.99	6.52	4.76	4.96
3	10.79	11.10	10.04	13.77	12.93
4	9.92	11.20	13.24	11.02	12.83
5	26.70	26.65	23.71	23.30	22.01
6	5.20	5.24	3.24	3.78	2.76

Performance Verification

			Model		
	25	36	50	75	100
R.C. - T.O. (fpm)	3138	3053	3064	3753	2584
R.C. - CR. (fpm)	984	573	1224	2150	1568
TOFL (ft)	3325	3414	3403	3484	3465
LFL (ft)	3365	3467	3468	3337	3370
$C_{L_{MAX_{TO}}}$	1.41	1.41	1.47	1.41	1.45
$C_{L_{MAX_{L}}}$	1.41	1.71	2.05	2.7	2.02

64						
65	V-TO	224.8	224.8	224.8	224.8	224.8
	V-A	224.8	224.8	224.8	224.8	224.8
67	V-MC	207.5	207.5	207.5	207.5	207.5

Appendix I

Airport Dimensions

Purpose: This appendix checks taxiway widths to determine what airports the twinbody configurations can operate from.

TABLE 3-1 **Characteristics of Principal Transport Aircraft**

Aircraft	Manufacturer	Wingspan	Length	Wheel base	Wheel track
DC-9-32	McDonnell-Douglas	93'04"	119'04"	53'02"	16'05"
DC-9-50	McDonnell-Douglas	93'04"	132'00"	60'11"	16'05"
DC-9-80	McDonnell-Douglas	107'10"	135'06"	72'05"	16'08"
DC-8-61	McDonnell-Douglas	148'05"	187'05"	77'06"	20'10"
DC-8-63	McDonnell-Douglas	148'05"	187'05"	77'06"	20'10"
DC-10-10	McDonnell-Douglas	155'04"	182'03"	72'05"	35'00"
DC-10-30	McDonnell-Douglas	161'04"	181'07"	72'05"	35'00"
B-737-200	Boeing	93'00"	100'00"	37'04"	17'02"
B-727-200	Boeing	108'00"	153'02"	63'03"	18'09"
B-720B	Boeing	130'10"	136'09"	50'08"	21'11"
B-707-120B	Boeing	130'10"	145'01"	52'04"	22'01"
B-707-320B	Boeing	142'05"	152'11"	59'00"	22'01"
B-757-200	Boeing	124'06"	153'10"	60'00"	24'00"
B-767-200	Boeing	156'04"	155'00"	64'07"	30'06"
B-747B	Boeing	195'09"	229'02"	84'00"	36'01"
B-747SP	Boeing	195'09"	176'07"	67'04"	36'01"
L-1011-100	Lockheed	155'04"	177'08"	70'00"	36'00"
L-1011-500	Lockheed	155'04"	164'02"	61'08"	36'00"
Caravelle-B	Aerospatiale	112'06"	108'03"	41'00"	17'00"
Trident 2E	Hawker-Siddeley	98'00"	114'09"	44'00"	19'01"
BAC111-200	British Aircraft	88'06"	92'06"	33'01"	14'03"
Super VC-10	British Aircraft	140'00"	171'08"	72'02"	21'05"
A-300	Airbus Industrie	147'01"	175'11"	61'01"	31'06"
A-310	Airbus Industrie	144'00"	153'01"	40'11"	31'06"
Concorde	British Aircraft-Aerospatial	83'10"	202'03"	59'08"	25'04"
Mercure	Dassault	100'02"	111'06"	39'01"	20'04"
Ilyushine-62	U.S.S.R.	141'09"	174'03"	80'04"	22'03"
Topolev-154	U.S.S.R.	123'02"	157'02"	62'01"	37'09"
Ilyushine-86	U.S.S.R.	157'08"	197'06"	70'00"	36'07"

* Approximate only; depends upon seating configuration.

' At sea level, standard day, no wind, level runway.

SOURCE: Manufacturers' data

also dictates the widths of runways and taxiways and the distances between these trafficways, and it affects the required turning radius on pavement curves. The passenger capacity has an important bearing on facilities within and adjacent to the terminal buildings. The runway length influences to a large part the land area required at an airport. The lengths provided in Tables 3-1 and 3-2 are only approximate. For more precise values the appropriate references, such as those listed in this chapter, should be consulted.

An examination of Tables 3-1 and 3-2 reveals some interesting information. The maximum takeoff weight of principal airline aircraft varies from 79,000 to 775,000 lb. Small general aviation aircraft weights range from 2000 to 8000 lb, while commuter and corporate aircraft vary from 15,000 to 74,600 lb. The maximum number of passengers carried by airline aircraft varies from 65 to nearly 500. On the other hand, small general aviation airplanes seat from 2 to 6 people, and short-haul and corporate aircraft from less than 10 to about 80 persons, depending on the configuration of the interior. Runway lengths for typical airline aircraft vary from 6000 to 12,000 ft, but it is important to note that it is not valid to assume that the larger the weight of an aircraft, the longer the runway length required. For large aircraft especially, the trip length has a profound influence on takeoff weight and, hence, the required runway length. Therefore, in the analysis of runway length requirements, an estimate of trip length is very important.

TABLE 3-1 **Continued**

Maximum structural takeoff weight, lb	Maximum landing weight, lb	Operating empty weight,* lb	Zero fuel weight, lb	Number and Type of engines	Maximum payload, passengers	Runway length' ft
108,000	99,000	56,855	87,000	2 TF	115–127	7,500
120,000	110,000	63,328	98,000	2 TF	130	7,100
140,000	128,000	77,797	118,000	2 TF	155–172	7,190
325,000	240,000	152,101	224,000	4 TF	196–259	11,000
355,000	258,000	158,738	230,000	4 TF	196–259	11,900
430,000	363,500	234,664	335,000	3 TF	270–345	9,000
555,000	403,000	261,094	368,000	3 TF	270–345	11,000
100,500	98,000	59,958	85,000	2 TF	86–125	5,600
169,000	150,000	97,400	138,000	3 TF	134–163	8,600
234,300	175,000	115,000	156,000	4 TF	131–149	6,100
257,340	190,000	127,500	170,000	4 TF	137–174	7,500
333,600	215,000	148,800	195,000	4 TF	141–189	11,500
220,000	198,000	130,700	184,000	2 TF	178–196	6,900
300,000	270,000	178,210	248,000	2 TF	211–230	6,700
775,000	564,000	365,800	526,000	4 TF	362–490	11,000
650,000	450,000	308,400	410,000	4 TF	288–364	8,000
466,000	243,133	243,133	320,000	3 TF	256–400	10,800
496,000	240,139	240,139	338,000	3 TF	246–400	9,300
123,460	100,130	66,260	87,080	2 TF	86–104	6,900
143,500	113,000	73,200	100,000	3 TF	82–115	7,500
79,000	69,000	46,405	64,000	2 TF	65–79	6,900
335,000	237,000	147,000	215,000	4 TF	100–163	8,200
302,000	281,000	186,810	256,830	2 TF	225–345	6,500
291,000	261,250	168,910	239,200	2 TF	205–265	6,100
389,000	240,000	175,000	200,000	4 TJ	108–128	11,300
114,640	108,030	57,022	99,200	2 TF	124–134	6,500
357,000	232,000	153,000	206,000	4 TF	168–186	10,700
198,416	185,188	95,900	139,994	3 TF	128–158	6,900
454,150	385,000			4 TF	350	8,600

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TABLE 3-2 Characteristics of General Aviation and Short-Haul Passenger Aircraft

Aircraft	Wing span	Fuselage length	Wheel track	Maximum takeoff weight, lb	Maximum number of seats*	Number and type of engines	Runway length, ft
Beech 23 Musketeer	32'09"	25'00"	11'10"	2,200	4	1 P	1,380
Beech V35 Bonanza	33'05"	26'04"	9'07"	3,400	6	1 P	1,320
Beech 58-Baron	37'10"	29'09"	11'00"	6,775	6	2 P	2,380
Beech B80-QueenAir	50'03"	35'06"	12'09"	8,800	11	2 P	1,800
Beech C90	45'10"	44'07"	13'00"	10,900	17	2 TP	2,800
Bellanca 260C	34'02"	22'11"	9'00"	3,000	4	1 P	1,000
Cessna 150	32'08"	23'00"	6'06"	1,600	2	1 P	1,385
Cessna 172 Skyhawk	35'09"	26'11"	7,02"	2,300	4	1 P	1,525
Cessna 182 Skylane	35'10"	28'00"	7'11"	2,950	4	1 P	1,350
Cessna T310	36'11"	29'06"	12'00"	5,500	6	2 P	1,790
Cessna 402	44'01"	36'05"	18'00"	6,850	10	2 P	2,485
Piper PA-23 Aztec	37'02"	30'03"	11'04"	5,200	6	2 P	1,250
Piper PA-28 Cherokee	30'00"	23'06"	10'00"	2,400	4	1 P	
Piper PA-28 Arrow	30'00"	24'02"	10'06"	2,600	4	1 P	
Piper Twin Comanche C	36'00"	25'02"	9'09"	3,600	6	2 P	1,870
Piper PA-31 Navajo	40'08"	32'07"	13'09"	6,500	6	2 P	2,095
Gulfstream II	68'10"	79'11"	13'08"	17,500	22	2 TF	4,070
Metroliner II	46'03"	59'05"	15'00"	12,500	22	2 TF	3,550
Lear Jet 25	35'07"	47'07"	8'03"	15,000	8	2 TJ	5,166
Lockheed Jet Star	54'05"	60'05"	12'03"	42,000	12	4 TJ	4,880
Sabreliner-60	44'05"	48'04"	7'02"	20,000	12	2 TJ	4,875
Jet Falcon 20T	54'03"	60'00"	12'03"	29,100	28	2 TF	4,430
deHavilland TwinOtter	65'00"	51'09"	12'02"	12,500	22	2 TP	1,200
Shorts 330–200	74'08"	58'01"		22,900	32	2 TF	3,880
BAe 146–100	85'05"	78'09"		74,600	84	4 TP	3,530
deHavilland DASH 7	93'00"	80'08"		44,500	52	4 TP	2,260
Fokker F27 Mk500	95'02"	82'03"		45,000	50	2 TP	5,460

* Including pilot.

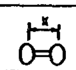
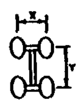
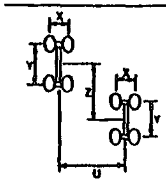
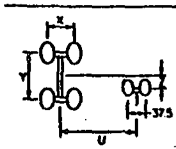
SOURCE: Manufacturers' data; *Jane's All the World's Aircraft* [27].

Runway lengths for small general aviation aircraft seldom exceed 2000 ft, while for commuter and corporate aircraft this length is on the order of 5000 ft.

In Tables 3-1 and 3-2 aircraft are referred to according to their type of propulsion and thrust-generating medium. The term *piston engine* applies to all propeller-driven aircraft powered by gasoline-fed reciprocating engines. Most small general aviation aircraft are powered by piston engines. The term *turboprop* refers to propeller-driven aircraft powered by turbine engines. A few twin-engine general aviation aircraft and a few of the earlier airline aircraft are powered in this manner. The term *turbojet* makes reference to those aircraft which are not dependent on propellers for thrust, but which obtain the thrust directly from a turbine engine. The early

jet airline aircraft, particularly the Comet 707 and the DC-8, were powered by turbojet engines, but these were discarded in favor of turbofan engines principally because the latter are far more economical. When a fan is added in the front or rear of a turbojet engine, it is referred to as a *turbofan*. Most fans are installed in front of the main engine. A fan can be thought of as a

TABLE 3-3 Main Landing Gear Dimensions for Typical Transport Aircraft

Main landing gear configuration	Aircraft	Dimensions, in X	Y	Z	U	Typical inflation pressures, psi
	DC-9-80	28.1				170
	B-737	30.5				148
	B-727	34.0				168
	DC-8-61	30.0	55.0			188
	DC-8-62	32.0	55.0			187
	DC-8-63	32.0	55.0			196
	DC-10-10	54.0	64.0			173
	B-720B	32.0	49.0			145
	B-707-120B	34.0	56.0			170
	B-707-320B	34.6	56.0			180
	B-757	34.0	45.0			161
	B-767	45.0	56.0			183
	Concorde	26.4	65.7			184
	L-1011-500	52.0	70.0			184
	A-300B	35.0	55.0			168
	B-747A	44.0	58.0	121.2	142.0	204
	B-747B, C, F	44.0	58.0	121.2	142.0	185
	DC-10-30	54.0	64.0	30.0	216.0	157*
	DC-10-40	54.0	64.0	30.0	216.0	165†

* Center gear tire pressure of 134 psi supports 18 percent of total weight.

† Center gear tire pressure of 140 psi supports 18 percent of total weight.

SOURCE: Manufacturers' data.

TABLE 9-3 **FAA Aircraft Approach Category Classification**

Approach category	Approach speed, kn
A	Less than 91
B	91–120
C	121–140
D	141–165
E	166 or greater

SOURCE: Federal Aviation Administration [22].

aircraft using the airport [9]. This classification system and the grouping of some common air-carrier aircraft into classifications are shown in Table 9-2.

Present Airport Classification System

The FAA is changing the classification of airports for geometric design purposes so that it is based upon the approach category of aircraft. The approach category, as shown in Table 9-3, is determined by the aircraft approach speed, which is defined as 1.3 times the stall speed in the landing configuration of that aircraft at maximum gross landing weight [23]. Aircraft with maximum certified takeoff weights in excess of 12,500 lb are classified as large aircraft; the rest are small aircraft.

Geometric design specifications for all aircraft in approach categories A and B are governed by utility airport specifications. Utility airports are now classified as basic utility stage I, basic utility stage II, general utility stage I and general utility stage II. A basic utility stage I airport accommodates about 75 percent of most single-engine aircraft and some small twin-engine aircraft for personal and business purposes. This airport is usually designed for aircraft in airplane design group I. A basic utility stage II airport includes a broader spectrum of small business and air taxi type twin-engine aircraft. This airport is normally designed for small aircraft through-

TABLE 9-4 **FAA Airplane Design Group Classification for Geometric Design for Airports**

Airplane design group	Wingspan, ft	Typical aircraft
I	Less than 49	Learjet 24, Rockwell Sabre 75A
II	49 but less than 79	Gulfstream II, Rockwell Sabre 80
III	79 but less than 118	B-727, B-737, BAC1-11, B-757, B-767, Concorde, L-1011, DC-9
IV	118 but less than 171	A-300, A-310, B-707, DC-8
V	171 but less than 197	B-747
VI	197 but less than 262	Future

SOURCE: Federal Aviation Administration [129, 23].

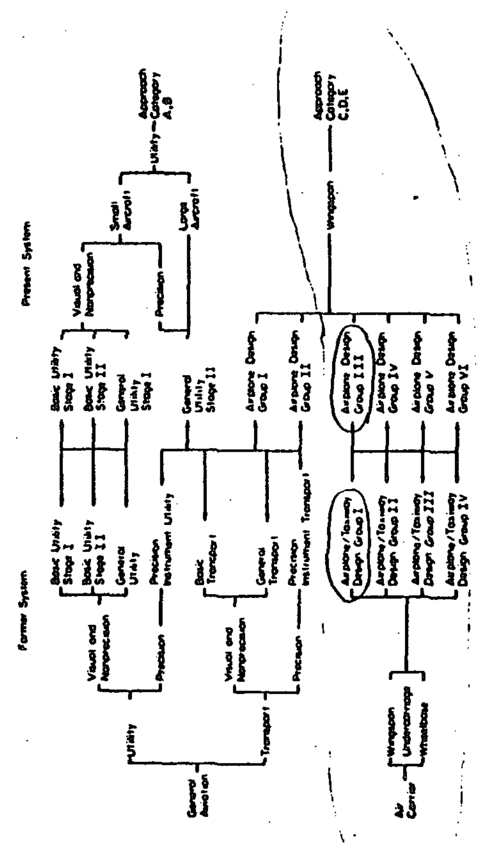


Fig. 9-1 Comparison between former and present FAA airport classification systems. (*Federal Aviation Administration*)

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Former Airport Classification System

For the purpose of geometric design standards, the FAA separated airport activity into two general classes, namely, general aviation and air carrier. A further breakdown was made within both of these categories.

Utility airports were defined as those which were used by aircraft weighing not more than 12,500 lb maximum certified takeoff weight, excluding jet aircraft [23]. *Transport airports* were defined as those which accommodated general aviation aircraft weighing more than 12,500 lb, and jet aircraft [11]. The utility airports were further grouped for visual and nonprecision instrument operations and for precision instrument operations. The visual and nonprecision instrument operation airports were called *basic utility stage* I, *basic utility stage* II, or *general utility*. A basic utility stage I airport had the capability of accommodating about 75 percent of the propeller aircraft not weighing more than 12,500 lb; in general this meant aircraft on the order of 3000 lb or less. A basic utility stage II airport had the capability of accommodating about 95 percent of the propeller aircraft weighing not more than 12,500 lb; in general this meant aircraft weighing on the order of 8000 lb or less. A general utility airport accommodated substantially all propeller aircraft not greater than 12,500 lb. A basic transport airport was one that could accommodate propeller or turbine-powered aircraft up to 60,000 lb maximum certified take off weight. This type of airport was planned for use by business jets, corporate jets, and executive jets. A general transport airport accommodated transport-category aircraft used for general aviation with maximum takeoff weights up to 150,000 lb or more. There were also specifications for a precision instrument transport category airport.

Air-carrier airports had been classified for geometric design purposes according to the wingspan, undercarriage width, and wheel base of the

TABLE 9-2 **Former FAA Taxiway Design Classification System for Air-Carrier Airports**

	Airplane/Taxiway Design Group			
	I	II	III	IV
Aircraft dimension, ft				
Wingspan	Up to 120	Up to 167	Up to 200	Up to 240
Undercarriage width	Up to 30	Up to 41	Up to 41	Up to 50
Wheelbase	Up to 60	Up to 87	Up to 87	Up to 104
Typical aircraft	B-727-100 B-737 BAC 1-11 CV 580 DC-9	B-707 B-727-200 B-757 B-767 DC-10 L-1011	B-747	Future

SOURCE: Federal Aviation Administration [9].

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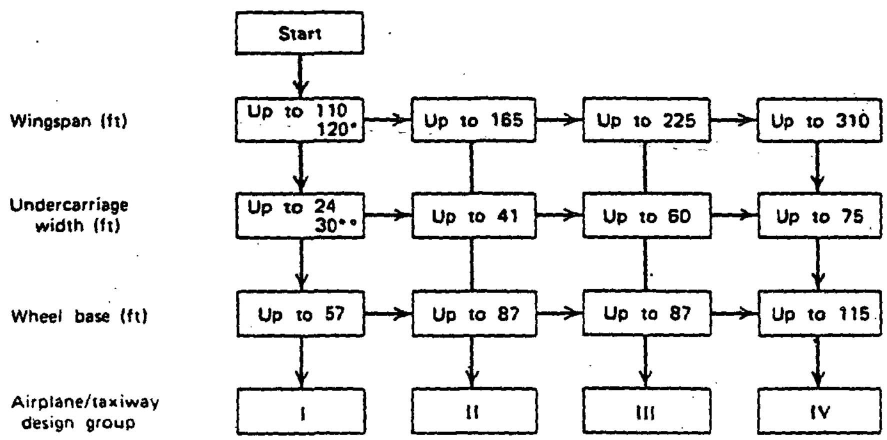
Table 7.5 Recommended Dimensional Standards for Airline Airports—Taxiways

Design Item	Symbol	Dimensional Criteria (ft) Airplane Taxiway Design Group I	II	III	IV
1. Taxiway structural pavement width on tangents	W_T	50	75	100	125
2. Taxiway structural pavement width on curves	W_C	65	90	115	140
3. Taxiway shoulder width	—	20	25	35	40
4. Safety area width	—	110	150	220	310
5. Taxiway and apron taxiway obstacle-free area width	—	210	270	360	470
6. Terminal taxilane obstacle-free area width	—	160	210	290	390
7. Separation distance from taxiway C_L to taxiway C_L	S_T	200	300	300	400
8. Separation distance from taxiway C_L to runway C_L	S_R	400	400	600	1,000
9. Radius of taxiway C_L curves	R	100	150	150	200



* (turboprop and piston aircraft only: 120)
** (turboprop and piston aircraft only: 30)
* Turboprop and piston airplanes only.

Source: *Airport Design Standards—Airports Served by Air Carriers—Taxiways,* FAA Advisory Circular AC 150/5335-1A, October 4, 1973.

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Table 7.6 FAA Minimum Dimensional Standards for General Aviation Airports

Design Item	Airport Group						Precision Runway for Basic or General Transport
	Basic Utility Stage I	Basic Utility Stage II	General Utility	Basic Transport A[b]	Basic Transport B[b]	General Transport	
Runway safety area width (ft)	100	120	150	150	300	300	500
Runway width (ft)	50	60	75	75	100	100	150
Taxiway width (ft)	20	30	40	40–60[a]	40–60[a]	40–60[a]	40–60[a]
Runway centerline to:							
Taxiway centerline (ft)	150	150	200	200	200	300	400
Airplane parking area (ft)	225	225	275	275	300	475	650
Building restriction line (ft)	200	200	250	250	300	350	750
Taxiway centerline to:							
Airplane parking area (ft)	75	75	75	75	100	175	250
Fixed or movable obstacle (ft)	50	50	50	50	75	100	200
Parallel taxiway (ft)	NA	NA	NA	150	150	200	300
Building restriction line (ft)	100	100	100	50	75	100	200

Sources: *Utility Airports*, FAA Advisory Circular AC 150/5300-4B, June 24, 1975; *Airport Design Standards—General Aviation Airports—Basic and General Transport*, FAA Advisory Circular AC 150/5300-6 including CHG 1, April 13, 1972.

[a] For aircraft tread widths exceeding 25 ft, use a 50 ft taxiway width; for tread widths exceeding 35 ft, use a 60 ft taxiway width.

[b] Basic Transport Column A is to be used only at those low activity sites where an existing utility runway, having no anticipated need for an instrument approach procedure of any kind, is extended for business jets. For all other basic transport airports use Column B.

Table 7.7 Runway Longitudinal Grade Design Criteria for Civilian Airports[a]

	Maximum Longitudinal Grade (%)	Maximum Grade, First and Last Quarter (%)	Maximum Effective Grade (%)	Maximum Change (%)	Distance Between Points of Intersection, *D* (ft)	Length of Vertical Curve[b] (ft/1% grade change)
FAA						
Air carrier airports	1.5	0.5	1.0	1.5	1000 (*A* + *B*)	1000
Basic and general transport airports	2.0	–	–	2.0	250 (*A* + *B*)	300
Utility airports	2.0	–	–	2.0	250 (*A* + *B*)	300
ICAO						
Code letter A	1.25	0.8	1.0	1.5	1000 (*A* + *B*)	1000
Code letter B	1.25	0.8	1.0	1.5	1000 (*A* + *B*)	1000
Code letter C	1.5	–	1.0	1.5	500 (*A* + *B*)	500
Code letter D	2.0	–	2.0	2.0	165 (*A* + *B*)	250
Code letter E	2.0	–	2.0	2.0	165 (*A* + *B*)	250

Sources: *Utility Airports*, FAA Advisory Circular AC 150/5300-4B, June 24, 1975; *Airport Design Standards—General Aviation Airports—Basic and General Transport*, FAA Advisory Circular AC 150/5300-6 including CHG 1, April 13, 1973; *Aerodromes*, Annex 14 to the International Convention on Civil Aviation, including Amendment 31, International Civil Aviation Organization, Montreal, Oct. 6, 1977.

[a] Runway grade changes shall also conform to sight distance criteria described in section 7.7.

[b] No vertical curve is required when grade change is less than 0.4%.

Table 7.3 ICAO Minimum Dimensional Recommended Practices

Design Item	A	B	C	D	E
	Code Letter				
Width of cleared and graded area					
Instrument runway (ft)	500	500	500	500	500
Noninstrument runway (ft)	500	500	400	260	200
Runway width (ft)	150	150	100	75	60
Taxiway width (ft)	75	75	50	33	25
Taxiway edge to:					
Edge of instrument runway (ft)	500	500	500	—	—
Edge of other runway (ft)	250	240	240	120	95
Edge of another taxiway (ft)	205	170	140	90	75
A fixed obstruction (ft)	125	100	85	60	53

Source: *Aerodromes*, Annex 14, to the International Convention on Civil Aviation including Amendment 31, International Civil Aviation Organization, Montreal, Oct. 6, 1977.

Table 7.4 FAA Recommended Dimensional Standards for Airline Airports—Runways

Runway safety area width (ft)	500
Runway width (ft)	150[a]
Runway centerline to:	
Building restriction line (ft)	750
Airplane parking area	Determined by imaginary surfaces (See FAR Part 77 and Ref. 6)
Property line	Determined by imaginary surfaces (See FAR Part 77 and Ref. 6)

Source: *Airport Design Standards—Airports Served by Air Carriers—Runway Geometrics*, FAA Advisory Circular AC 150/5335-4, including CHG 1, June 14, 1976.

[a] A 200 ft runway width is recommended where airplanes in Design Group III (see Table 7.5) are planned to be accommodated.

TABLE 9-5 **Runway Dimensional Standards**

	International Civil Aviation Organization				Federal Aviation Administration									
					Approach categories A, B, utility				Approach categories C, D, E, transport					
					Visual and Nonprecision		Precision							
	1	2	3	4	I	II	I	II	I	II	III	IV	V	VI
Width														
Pavement[a]	60–75	75–100	100–150	150	60	75	75	100	100	100	100	150	150	200
Safety area[b]	200	270	500	500	120	150	300	300	500	500	500	500	500	500
Shoulder[c]									10	10	20	25	35	40
Gradient, %														
Pavement, longitudinal														
maximum	2.0	2.0	1.5	1.25	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5
maximum effective	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0
maximum change	2.0	2.0	1.5	1.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5
transition curve rate of slope change per 100 ft	0.4	0.4	0.2	0.1	0.33	0.33	0.33	0.33	0.1	0.1	0.1	0.1	0.1	0.1
Pavement, transverse														
maximum[d]					2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5	
Safety area														
maximum longitudinal	2.0	2.0	1.75	1.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5
maximum transverse	3.0	3.0	2.5	2.5	5.0	5.0	5.0	5.0	3.0	3.0	3.0	3.0	3.0	3.0

[a] At least 100 ft for precision instrument.
[b] Precision and nonprecision approach requires 500 ft for code 1 and 2, and 1000 ft for codes 3 and 4.
[c] Pavement and shoulders should be at least 200 ft for codes D and E.
[d] 2.0 for codes A and B, 1.5 for codes C, D, and E.
SOURCES: International Civil Aviation Organization [4] and Federal Aviation Administration [12, 23].

may be sited in accordance with the continuous visibility requirements. A clear line of sight to taxi-lane centerlines is also desirable. This requirement may be satisfied where adequate control of aircraft exists by other means [12].

RUNWAYS

The runway system at an airport consists of the structural pavement, the shoulders, the blast pad, and the runway safety area, as shown in Fig. 9-2.

1. The structural pavement supports the aircraft with respect to structural load, maneuverability, control, stability, and other operational and dimensional criteria.

2. The shoulder adjacent to the end of the structural pavement resists jet blast erosion and accommodates maintenance and emergency equipment.

3. The blast pad is an area designed to prevent erosion of the surfaces adjacent to the ends of runways which are subjected to sustained or repeated jet blast. The ICAO requires a 100-ft blast pad, whereas the FAA has determined that the blast pad should be 100 ft in length for airplane design group I, 150 ft for design group II, 200 ft for design groups III and

IV, and 400 ft for design groups V and VI. The width of the blast pad should include both the runway and the shoulder width.

4. The runway safety area is an area which is cleared, drained, and graded, and which includes the structural pavement, shoulders, blast pad, and stopway, if provided. This area should be capable of supporting emergency and maintenance equipment as well as providing support for aircraft should they veer off the pavement for one reason or another. The runway safety area required by the ICAO is 275 ft beyond each end of the runway for code elements 3 and 4, and for all runways with instrument operations. The FAA requires that the runway safety area extend 240 ft beyond the end of the runway for small aircraft in airplane design group I, 300 ft for small aircraft in design group II, and 600 ft for precision instrument operations with small aircraft. It also requires 1000 ft for large aircraft in all design groups. The runway safety areas should include the blast pad and its width should be 500 ft for transport category aircraft.

The ICAO and FAA runway standards related to pavement and safety area widths, as well as longitudinal and transverse gradients, are given in Table 9-5.

Sight Distance and Longitudinal Profile

In addition to the information given in Table 9-5, there are other factors that must be considered when establishing the longitudinal profile. One is