CLASS II DESIGN UPDATE
FOR THE FAMILY OF COMMUTER AIRPLANES

PREPARED FOR: NASA GRANT NGT-8001

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# Table of Contents

List of Symbols iii

1.0 Introduction 1

2.0 Class II Configuration Descriptions 5
   2.1 Review of Common Design Features 6
      2.1.1 Common Structural Component Features 6
      2.1.2 Common Flight System Designs 21
         2.1.2.1 Interior Layouts 21
         2.1.2.2 Landing Gear System 21
         2.1.2.3 Fuel System 22
         2.1.2.4 Flight Control System 22
         2.1.2.5 Hydraulic System 22
         2.1.2.6 Pressurization System 22
         2.1.2.7 De-icing System 23
   2.2 Presentation of Class II Threeviews 25

3.0 Mass Properties 38
   3.1 Weight and Balance 38
   3.2 Inertias 38
   3.3 Take-off Weight Sensitivities 39

4.0 Stability and Control Considerations 48
   4.1 Commonality Considerations 48
   4.2 Wing Maximum Lift 49
   4.3 Wing Lift Curves 50
   4.4 Trim Diagrams 50
   4.5 Open Loop Handling Qualities 70
   4.6 Take-off Rotation 71
   4.7 Engine-out Requirements 71
   4.8 Roll Performance 72
      4.8.1 Lateral Acceleration of the Twinbody Configurations 73

5.0 Stick Forces and Gradients 74
   5.1 Hinge Moments 74
   5.2 Longitudinal Stick Forces 75
   5.3 Rudder Pedal Forces 76
   5.4 Aileron Wheel Forces 77
   5.5 Stick Force Commonality 77

6.0 Class II Drag Prediction 79

7.0 Verification of Mission Performance 91
   7.1 Field Length Verification 91
   7.2 Verification of FAR 25 Climb Requirements 93
   7.3 Verification of Range Requirements 93
   7.4 Rate of Climb Requirements 95

8.0 Commonality Analysis of the Commuter Family 97
   8.1 Summary of Weight Penalties and Cost Savings Due to Commonality 99
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Aspect ratio</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>Wing span</td>
<td>ft</td>
</tr>
<tr>
<td>b_a</td>
<td>Aileron span</td>
<td>ft</td>
</tr>
<tr>
<td>b_f</td>
<td>Flap span</td>
<td>ft</td>
</tr>
<tr>
<td>b_t</td>
<td>Tire width</td>
<td>ft</td>
</tr>
<tr>
<td>c</td>
<td>Wing chord</td>
<td>ft</td>
</tr>
<tr>
<td>c</td>
<td>Wing mean geometric chord</td>
<td>ft</td>
</tr>
<tr>
<td>c_f</td>
<td>Flap chord</td>
<td>ft</td>
</tr>
<tr>
<td>c_f</td>
<td>Equivalent skin friction coefficient</td>
<td></td>
</tr>
<tr>
<td>c_f</td>
<td>Specific fuel consumption</td>
<td>lbs/lbs/hr</td>
</tr>
<tr>
<td>C_d</td>
<td>Drag coefficient</td>
<td></td>
</tr>
<tr>
<td>C_d_0</td>
<td>Zero lift drag coefficient</td>
<td></td>
</tr>
<tr>
<td>c_l</td>
<td>Section lift coefficient</td>
<td></td>
</tr>
<tr>
<td>c_l_a</td>
<td>Section lift curve slope</td>
<td>1/rad</td>
</tr>
<tr>
<td>c_l_f</td>
<td>Section lift curve slope with flaps down</td>
<td>1/rad</td>
</tr>
<tr>
<td>C_l</td>
<td>Lift Coefficient</td>
<td></td>
</tr>
<tr>
<td>C_m</td>
<td>Pitching moment coefficient</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Drag</td>
<td>lbs</td>
</tr>
<tr>
<td>D_p</td>
<td>Propeller diameter</td>
<td>ft</td>
</tr>
<tr>
<td>D_t</td>
<td>Tire diameter</td>
<td>ft</td>
</tr>
<tr>
<td>d_f</td>
<td>fuselage diameter</td>
<td>ft</td>
</tr>
<tr>
<td>e</td>
<td>Oswald's efficiency factor</td>
<td></td>
</tr>
<tr>
<td>e</td>
<td>Endurance</td>
<td>hours</td>
</tr>
<tr>
<td>E</td>
<td>Equivalent parasite area</td>
<td>ft^2</td>
</tr>
<tr>
<td>FAR</td>
<td>Federal Air Regulation</td>
<td></td>
</tr>
<tr>
<td>g</td>
<td>Acceleration of gravity</td>
<td>ft/sec^2</td>
</tr>
<tr>
<td>h</td>
<td>Altitude</td>
<td>ft</td>
</tr>
<tr>
<td>i_w</td>
<td>Wing incidence angle</td>
<td>degrees</td>
</tr>
<tr>
<td>k_A</td>
<td>Sweep angle correction factor</td>
<td></td>
</tr>
<tr>
<td>k_f</td>
<td>Correction factor for split flaps</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>Lift</td>
<td>lbs</td>
</tr>
<tr>
<td>L/D</td>
<td>Lift-to-drag ratio</td>
<td></td>
</tr>
<tr>
<td>l_f</td>
<td>Fuselage length</td>
<td>ft</td>
</tr>
<tr>
<td>l_f_c</td>
<td>Fuselage cone length</td>
<td>ft</td>
</tr>
<tr>
<td>l_m</td>
<td>Dist. c.g. to main gear</td>
<td>ft</td>
</tr>
</tbody>
</table>
\begin{itemize}
\item \( l_n \) \hspace{1cm} \text{Dist. c.g. to nose gear} \hspace{1cm} \text{ft}
\item \( M \) \hspace{1cm} \text{Mach number} \hspace{1cm} \text{-----}
\item \( n \) \hspace{1cm} \text{Load factor} \hspace{1cm} \text{-----}
\item \( \text{nm} \) \hspace{1cm} \text{Nautical mile (6,076 ft)} \hspace{1cm} \text{nm}
\item \( n_p \) \hspace{1cm} \text{Number of propeller blades} \hspace{1cm} \text{-----}
\item \( n_s \) \hspace{1cm} \text{Number of struts} \hspace{1cm} \text{-----}
\item \( N \) \hspace{1cm} \text{Number of engines} \hspace{1cm} \text{-----}
\item \( P \) \hspace{1cm} \text{Power, horse-power} \hspace{1cm} \text{hp}
\item \( P_{bl} \) \hspace{1cm} \text{Blade power loading} \hspace{1cm} \text{hp/ft}^2
\item \( q \) \hspace{1cm} \text{Dynamic pressure} \hspace{1cm} \text{psf}
\item \( R \) \hspace{1cm} \text{Range} \hspace{1cm} \text{nm}
\item \( R_n \) \hspace{1cm} \text{Reynold's number} \hspace{1cm} \text{-----}
\item \( RC \) \hspace{1cm} \text{Rate of climb} \hspace{1cm} \text{fpm or fps}
\item \( S \) \hspace{1cm} \text{Distance} \hspace{1cm} \text{ft}
\item \( S_{SHP} \) \hspace{1cm} \text{Shaft horsepower} \hspace{1cm} \text{hp}
\item \( S_{sw} \) \hspace{1cm} \text{Wetted area} \hspace{1cm} \text{ft}^2
\item \( S_{swf} \) \hspace{1cm} \text{Flapped wing area} \hspace{1cm} \text{ft}^2
\item \( t \) \hspace{1cm} \text{Time} \hspace{1cm} \text{sec, min, hr}
\item \( t/c \) \hspace{1cm} \text{Thickness ratio} \hspace{1cm} \text{-----}
\item \( T \) \hspace{1cm} \text{Thrust} \hspace{1cm} \text{lbs}
\item \( V \) \hspace{1cm} \text{True airspeed} \hspace{1cm} \text{mph, fps, kts}
\item \( V_s \) \hspace{1cm} \text{Volume coefficient} \hspace{1cm} \text{-----}
\item \( W \) \hspace{1cm} \text{Weight} \hspace{1cm} \text{lbs}
\item \( X_{ac} \) \hspace{1cm} \text{Distance from l.e. c to aerodynamic center} \hspace{1cm} \text{ft, in}
\item \( x, y, z \) \hspace{1cm} \text{Distance from reference to a component c.g.} \hspace{1cm} \text{ft, in}
\item \( x_v, x_h, x_c \) \hspace{1cm} \text{Distance from c.g. to a.c. of a surface} \hspace{1cm} \text{ft, in}
\item \( Y_t \) \hspace{1cm} \text{Engine-out moment arm} \hspace{1cm} \text{ft}
\end{itemize}

\textbf{Greek Symbols}

\begin{itemize}
\item \( \alpha \) \hspace{1cm} \text{angle of attack} \hspace{1cm} \text{deg, rad}
\item \( \beta \) \hspace{1cm} \text{sideslip angle} \hspace{1cm} \text{deg, rad}
\item \( \delta \) \hspace{1cm} \text{control surface deflection} \hspace{1cm} \text{deg, rad}
\item \( \lambda \) \hspace{1cm} \text{taper ratio} \hspace{1cm} \text{-----}
\item \( \Lambda \) \hspace{1cm} \text{sweep angle} \hspace{1cm} \text{deg, rad}
\item \( \pi \) \hspace{1cm} \text{3.142} \hspace{1cm} \text{-----}
\item \( \Gamma \) \hspace{1cm} \text{dihedral angle} \hspace{1cm} \text{deg, rad}
\item \( \rho \) \hspace{1cm} \text{air density} \hspace{1cm} \text{slugs/ft}^3
\item \( \sigma \) \hspace{1cm} \text{air density ratio} \hspace{1cm} \text{-----}
\item \( \theta_{fc} \) \hspace{1cm} \text{fuselage cone angle} \hspace{1cm} \text{deg, rad}
\item \( \theta \) \hspace{1cm} \text{lateral ground clearance angle} \hspace{1cm} \text{deg, rad}
\item \( \theta \) \hspace{1cm} \text{longitudinal ground clearance angle} \hspace{1cm} \text{deg, rad}
\item \( \theta_{lof} \) \hspace{1cm} \text{lift-off angle} \hspace{1cm} \text{deg, rad}
\end{itemize}
\( \varepsilon \)  
Downwash angle

\( \gamma_t \)  
twist angle

\( \eta \)  
spanwise station, fraction
of the span

\( \psi \)  
lateral tip-over angle

\( \gamma \)  
flight path angle

\( \lambda \)  
bypass ratio

Subscripts

\( a \)  
aileron

\( A \)  
approach

\( \text{abs} \)  
absolute

\( \text{cat} \)  
catapult

\( \text{cl} \)  
climb

\( \text{cr} \)  
cruise

\( \text{crew} \)  
crew

\( \text{crit} \)  
critical

\( c/2 \)  
semi-chord

\( c/4 \)  
quarterchord

\( \text{des} \)  
design

\( \text{dry} \)  
without fluids or afterburner

\( e \)  
elevator

\( E \)  
empty

\( f \)  
flaps

\( \text{ff} \)  
fuel fraction

\( F \)  
mission fuel

\( \text{FL} \)  
field length

\( \text{guess} \)  
guessed

\( h \)  
alitude

\( \text{le} \)  
leading edge

\( L \)  
landing

\( \text{LG} \)  
landing, ground

\( \text{LO} \)  
flight-off

\( \text{max} \)  
maximum

\( \text{ME} \)  
manufacturer's empty

\( \text{OE} \)  
operating empty

\( \text{PA} \)  
power approach

\( \text{PL} \)  
payload

\( \text{RC} \)  
rate of climb

\( r \)  
root

\( \text{res} \)  
reserve

\( \text{reqd} \)  
required

\( s \)  
stall

\( \text{TD} \)  
take-off

\( \text{TOG} \)  
take-off, ground

\( t \)  
tip

\( \text{te} \)  
trailing edge

\( \text{tent} \)  
tentative

\( \text{tfo} \)  
trapped fuel and oil

\( \text{used} \)  
used

\( w \)  
wing
wet  wetted
wb  wing-body
wod  wind over the deck

**Acronyms**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEO</td>
<td>All engines operating</td>
</tr>
<tr>
<td>APU</td>
<td>Auxiliary power unit</td>
</tr>
<tr>
<td>B.L.</td>
<td>Buttock line</td>
</tr>
<tr>
<td>c.g.</td>
<td>Center of gravity</td>
</tr>
<tr>
<td>F.S.</td>
<td>Fuselage station, Front spar</td>
</tr>
<tr>
<td>OEI</td>
<td>One engine inoperative</td>
</tr>
<tr>
<td>OWE</td>
<td>Operating weight empty</td>
</tr>
<tr>
<td>PAX</td>
<td>Passengers</td>
</tr>
<tr>
<td>p.d.</td>
<td>Preliminary design</td>
</tr>
<tr>
<td>R.S.</td>
<td>Rear Spar</td>
</tr>
<tr>
<td>sls</td>
<td>Sea level standard</td>
</tr>
<tr>
<td>TBP</td>
<td>Turboprop</td>
</tr>
<tr>
<td>W.L.</td>
<td>Waterline</td>
</tr>
</tbody>
</table>
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) Tricycle 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
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

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

*The twinbody airplanes require a wing centerpiece of 590 ft²

**The twinbody airplanes require a horizontal tail bar of 290 ft²

***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

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

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.
NOTE: ALL DIMENSIONS IN INCHES.

Figure 2.3 5500 SHP PD436-11 Derivative Outline Drawing

G.SWIFT 2-6-87
Figure 2.4 11000 SHP PD436-11 Derivative Outline Drawing

G.SWIFT 2-6-87
Wing Geometry

\[ S = 592 \text{ ft}^2 \]
\[ b = 84.3 \text{ ft} \]
\[ A = 12 \]
\[ \bar{c} = 7.45 \]
\[ t/c = .13 \]
\[ \lambda = .40 \]
\[ \theta_{LE} = 15 \text{ deg} \]
\[ \frac{S_a}{S} = 6.25 \text{ ft}^2 \]
\[ C_{sp}/c = .10 \]
\[ \frac{S_{sp}}{S} = 7.67 \text{ ft}^2 \]
\[ c_{f}/c = .30 \]

\[ R_{N_{CR}} = 20 \times 10^6 \quad \text{(root chord)} \]

\[ R_{N_{CR}} = 8 \times 10^6 \quad \text{(tip chord)} \]

**Figure 2.8 Wing Layout**
### Geometry of the Empennage

<table>
<thead>
<tr>
<th></th>
<th>H-Tail</th>
<th>V-Tail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area, ft²</td>
<td>120</td>
<td>170</td>
</tr>
<tr>
<td>Span, ft</td>
<td>26.6</td>
<td>18.4</td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td>5.88</td>
<td>1.4</td>
</tr>
<tr>
<td>Taper Ratio</td>
<td>0.50</td>
<td>0.33</td>
</tr>
<tr>
<td>M.G.C., ft</td>
<td>4.66</td>
<td>12.0</td>
</tr>
<tr>
<td>L.E. Sweep, deg</td>
<td>20.0</td>
<td>40.0</td>
</tr>
<tr>
<td>Thickness Ratio</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>Root Chord, ft</td>
<td>6.02</td>
<td>16.6</td>
</tr>
<tr>
<td>Spar Box Length:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>root, in</td>
<td>27</td>
<td>88</td>
</tr>
<tr>
<td>tip, in</td>
<td>13</td>
<td>27</td>
</tr>
<tr>
<td>Elevator Chord Ratio</td>
<td>.35</td>
<td>.35</td>
</tr>
<tr>
<td>Elevator Area, ft²</td>
<td>42.0</td>
<td>59.5</td>
</tr>
<tr>
<td>Rudder Chord Ratio</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rudder Area, ft²</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Figure 2.11](image_url)

**Common Tailcone-Engine Integration**

for the 25, 36, and 50 Pax Models
Figure 2.12

Tailcone Arrangement for
the Twin-Body Models
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 acquisition 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 necessary 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 details 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.
### TABLE 2.3 TABLE OF GEOMETRY FOR THE 25 PASSENGER COMMUTER

<table>
<thead>
<tr>
<th></th>
<th>WING</th>
<th>HORIZONTAL TAIL</th>
<th>VERTICAL TAIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S$ ft$^2$</td>
<td>592</td>
<td>120</td>
<td>170</td>
</tr>
<tr>
<td>$b$ ft</td>
<td>84.3</td>
<td>26.6</td>
<td>15.4</td>
</tr>
<tr>
<td>$	ilde{c}$ ft</td>
<td>7.45</td>
<td>4.68</td>
<td>12</td>
</tr>
<tr>
<td>$A$</td>
<td>12</td>
<td>5.88</td>
<td>1.40</td>
</tr>
<tr>
<td>$\lambda_{LE}$</td>
<td>15°</td>
<td>25°</td>
<td>45°</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>.4</td>
<td>.5</td>
<td>.33</td>
</tr>
<tr>
<td>$t/c$</td>
<td>.13</td>
<td>.11</td>
<td>.11</td>
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</table>

<table>
<thead>
<tr>
<th>Airfoil</th>
<th>NLF</th>
<th>NLF (inv)</th>
<th>NLF (sym)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Gamma$</td>
<td>3°</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>$i$</td>
<td>0°</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>$\varepsilon_t$</td>
<td>-3°</td>
<td>0°</td>
<td>0°</td>
</tr>
</tbody>
</table>

- 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

<table>
<thead>
<tr>
<th></th>
<th>FUSELAGE</th>
<th>CABIN INTERIOR</th>
<th>OVERALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length ft</td>
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<td>28.7</td>
<td>72.6</td>
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<td>Height in</td>
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<td>76</td>
<td>320</td>
</tr>
<tr>
<td>Width in</td>
<td>96</td>
<td>91</td>
<td>852</td>
</tr>
</tbody>
</table>
Figure 2.17 36 Passenger Class II Threeview
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<th>HORIZONTAL TAIL</th>
<th>VERTICAL TAIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S$ ft$^2$</td>
<td>592</td>
<td>120</td>
<td>170</td>
</tr>
<tr>
<td>$b$ ft</td>
<td>84.3</td>
<td>26.6</td>
<td>15.4</td>
</tr>
<tr>
<td>$c$ ft</td>
<td>7.45</td>
<td>4.68</td>
<td>12</td>
</tr>
<tr>
<td>$A$</td>
<td>12</td>
<td>5.88</td>
<td>1.40</td>
</tr>
<tr>
<td>$\Lambda_{LE}$</td>
<td>15$^\circ$</td>
<td>25$^\circ$</td>
<td>45$^\circ$</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>.4</td>
<td>.5</td>
<td>.33</td>
</tr>
<tr>
<td>$t/c$</td>
<td>.13</td>
<td>.11</td>
<td>.11</td>
</tr>
<tr>
<td>Luftspantyp</td>
<td>NLF</td>
<td>NLF (inv)</td>
<td>NLF (sym)</td>
</tr>
<tr>
<td>$\Gamma$</td>
<td>3$^\circ$</td>
<td>0$^\circ$</td>
<td>0$^\circ$</td>
</tr>
<tr>
<td>$i$</td>
<td>0$^\circ$</td>
<td>0$^\circ$</td>
<td>0$^\circ$</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>-3$^\circ$</td>
<td>0$^\circ$</td>
<td>0$^\circ$</td>
</tr>
</tbody>
</table>

**Elevator chord ratio** 0.35
**Rudder chord ratio** 0.35

**Aileron:** chord ratio 0.30
span ratio 0.85 to 0.92

**Spoiler:** chord ratio 0.10
span ratio 0.50 to 0.85

**Flap:** chord ratio 0.30
span ratio 0.11 to 1.0

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<thead>
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<th>FUUSELAGE</th>
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<th>OVERALL</th>
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</thead>
<tbody>
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<td>80.6</td>
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<tr>
<td>Height in</td>
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<td>76</td>
<td>320</td>
</tr>
<tr>
<td>Width in</td>
<td>96</td>
<td>91</td>
<td>852</td>
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</table>
Figure 2.18 50 Passenger Class II Threeview
### TABLE 2.5  TABLE OF GEOMETRY FOR THE 50 PASSENGER COMMUTER

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<th>VERTICAL TAIL</th>
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<tr>
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<td>120</td>
<td>170</td>
</tr>
<tr>
<td>$b \ ft$</td>
<td>84.3</td>
<td>26.6</td>
<td>15.4</td>
</tr>
<tr>
<td>$c \ ft$</td>
<td>7.45</td>
<td>4.68</td>
<td>12.0</td>
</tr>
<tr>
<td>A</td>
<td>12</td>
<td>5.88</td>
<td>1.40</td>
</tr>
<tr>
<td>$\alpha_{LE}$</td>
<td>15°</td>
<td>25°</td>
<td>45°</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>.4</td>
<td>.7</td>
<td>.3</td>
</tr>
<tr>
<td>t/c</td>
<td>.13</td>
<td>.11</td>
<td>.11</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Airfoil</th>
<th>NLF</th>
<th>NLF (inv)</th>
<th>NLF (sym)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Gamma$</td>
<td>3°</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>$i$</td>
<td>0°</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>$\epsilon_t$</td>
<td>-3°</td>
<td>0°</td>
<td>0°</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>FUSELAGE</th>
<th>CABIN INTERIOR</th>
<th>OVERALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length ft</td>
<td>96.9</td>
<td>54.2</td>
</tr>
<tr>
<td>Height in</td>
<td>96</td>
<td>76</td>
</tr>
<tr>
<td>Width in</td>
<td>96</td>
<td>91</td>
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</table>
Figure 2.19 75 Passenger Class II Threeview
## Table 2.6 Table of Geometry for the 75 Passenger Commuter

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<tbody>
<tr>
<td>S $ft^2$</td>
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<td>410</td>
<td>340</td>
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<tr>
<td>b $ft$</td>
<td>132.5</td>
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<td>15.4</td>
</tr>
<tr>
<td>c $ft$</td>
<td>8.97</td>
<td>5.63</td>
<td>12</td>
</tr>
<tr>
<td>A</td>
<td>14.85</td>
<td>13.6</td>
<td>1.40</td>
</tr>
<tr>
<td>$\Lambda_{LE}$</td>
<td>11.5°</td>
<td>4°</td>
<td>45°</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>.4</td>
<td>.5</td>
<td>.33</td>
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<tr>
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<td>.11</td>
<td>.11</td>
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<tr>
<td>Airfoil</td>
<td>NLF</td>
<td>NLF (inv)</td>
<td>NLF (sym)</td>
</tr>
<tr>
<td>$\Gamma$</td>
<td>3°</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>$i$</td>
<td>0°</td>
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</tr>
<tr>
<td>$\epsilon_t$</td>
<td>-3°</td>
<td>0°</td>
<td>0°</td>
</tr>
</tbody>
</table>

- Elevator chord ratio: 0.35
- Rudder chord ratio: 0.35

Aileron: chord ratio: 0.30
Span ratio: 0.91 to 0.98

Spoiler: chord ratio: 0.10
Span ratio: 0.50 to 0.90

Flap: chord ratio: 0.30
Span ratio: 0.11 to 1.0

<table>
<thead>
<tr>
<th></th>
<th>Fuselage</th>
<th>Cabin Interior</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length ft</td>
<td>79.4</td>
<td>36.7</td>
<td>80.6</td>
</tr>
<tr>
<td>Height in</td>
<td>96</td>
<td>76</td>
<td>320</td>
</tr>
<tr>
<td>Width in</td>
<td>96</td>
<td>91</td>
<td>852</td>
</tr>
</tbody>
</table>
### Table 2.7 Table of Geometry for the 100 Passenger Commuter

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<th>Horizontal Tail</th>
<th>Vertical Tail</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S$ ft$^2$</td>
<td>1182</td>
<td>410</td>
<td>340</td>
</tr>
<tr>
<td>$b$ ft</td>
<td>132.5</td>
<td>74.77</td>
<td>15.4</td>
</tr>
<tr>
<td>$c$ ft</td>
<td>8.97</td>
<td>5.63</td>
<td>12</td>
</tr>
<tr>
<td>$A$</td>
<td>14.85</td>
<td>13.6</td>
<td>1.40</td>
</tr>
<tr>
<td>$\lambda_{LE}$</td>
<td>11.5°</td>
<td>4°</td>
<td>45°</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>.4</td>
<td>.5</td>
<td>.33</td>
</tr>
<tr>
<td>$t/c$</td>
<td>.13</td>
<td>.11</td>
<td>.11</td>
</tr>
<tr>
<td>Airfoil</td>
<td>NLF</td>
<td>NLF (inv)</td>
<td>NLF (sym)</td>
</tr>
<tr>
<td>$\Gamma$</td>
<td>3°</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>$i$</td>
<td>0°</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>$\varepsilon_t$</td>
<td>-3°</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>elevator chord</td>
<td>rudder chord</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ratio .35</td>
<td>ratio .35</td>
</tr>
<tr>
<td>Aileron: chord ratio</td>
<td>.30</td>
<td>span ratio .91 to .98</td>
<td></td>
</tr>
<tr>
<td>Spoiler: chord ratio</td>
<td>.10</td>
<td>span ratio .50 to .90</td>
<td></td>
</tr>
<tr>
<td>Flap: chord ratio</td>
<td>.30</td>
<td>span ratio .11 to 1.0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Fuselage</th>
<th>Cabin Interior</th>
<th>Overall</th>
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</thead>
<tbody>
<tr>
<td>Length ft</td>
<td>96.9</td>
<td>54.2</td>
<td>98.2</td>
</tr>
<tr>
<td>Height in</td>
<td>96</td>
<td>76</td>
<td>320</td>
</tr>
<tr>
<td>Width in</td>
<td>96</td>
<td>91</td>
<td>852</td>
</tr>
</tbody>
</table>
$W_{TO} = 82,500 \text{ lbs}$

$S = 1178 \text{ ft}^2$

$c = 10.5 \text{ ft}$

$S_H = 363 \text{ ft}^2$

$S_V = 363 \text{ ft}^2$

$b = 119 \text{ ft}$

$l_f = 108 \text{ ft}$

**Figure 2.21** 3-View of the 75 Passenger Model
$W_{TO} = 112,300$ lbs
$S = 1604 \text{ ft}^2$
$ar{c} = 11.6 \text{ ft}$
$S_H = 155 \text{ ft}^2$
$S_V = 300 \text{ ft}^2$
$b = 139 \text{ ft}$
$l_f = 126 \text{ ft}$

**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

<table>
<thead>
<tr>
<th>Model</th>
<th>Ixx</th>
<th>Iyy</th>
<th>Izz</th>
<th>Ixx</th>
<th>Iyy</th>
<th>Izz</th>
</tr>
</thead>
<tbody>
<tr>
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<td>131896</td>
<td>188392</td>
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<td>121578</td>
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<td>36</td>
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<td>237382</td>
<td>339291</td>
<td>69710</td>
<td>207940</td>
<td>255999</td>
</tr>
<tr>
<td>50</td>
<td>141865</td>
<td>465510</td>
<td>580046</td>
<td>73363</td>
<td>408670</td>
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<td>75</td>
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<td>505928</td>
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<td>100</td>
<td>1646875</td>
<td>769820</td>
<td>2326135</td>
<td>888448</td>
<td>653359</td>
<td>1455491</td>
</tr>
</tbody>
</table>

*Inertias in slug-ft²

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>
<thead>
<tr>
<th>Table 3.2 - Take-off Weight Sensitivities Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>( \frac{\Delta W_{TO}}{\Delta W_{PL}} )</td>
</tr>
<tr>
<td>( \frac{\Delta W_{TO}}{\Delta W_{E}} )</td>
</tr>
<tr>
<td>( \frac{\Delta W_{TO}}{\Delta R} )</td>
</tr>
<tr>
<td>( \frac{\Delta W_{TO}}{\Delta c_p} )</td>
</tr>
<tr>
<td>( \frac{\Delta W_{TO}}{\Delta L/D} )</td>
</tr>
<tr>
<td>( \frac{\Delta W_{TO}}{\Delta \eta_p} )</td>
</tr>
</tbody>
</table>
Figure 3.1 Center of Gravity Excursion Diagram for the 25 Passenger Model

WEIGHT W = 16,000 LBS.
Figure 3.2 Center of Gravity Excursion Diagram for the 36 Passenger Model
Figure 3.3 Center of Gravity
Excursion Diagram for the
50 Passenger Model
Figure 3.4 Center of Gravity Excursion Diagram for the 75 Passenger Model.
Figure 3.5 Center of Gravity Excursion Diagram for the 100 Passenger Model
Figure 3.7 Pitching 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 requirements 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 $C_{L_{\text{max}}}$ is 1.5. The cruise $C_{L_{\text{max}}}$ of the wing is 1.25. During initial performance sizing of the baseline configurations, a clean $C_{L_{\text{max}}}$ of 1.4 was assumed for all the airplanes. The wing design incorporated into the commuter family will generate the required clean $C_{L_{\text{max}}}$. The flap deflections used on each airplane are listed in Table 4.1. These flap settings were selected to obtain the needed increment in $C_{L_{\text{max}}}$ to meet the field length requirements.
Table 4.1 - Flap Deflections for the Commuter Family

<table>
<thead>
<tr>
<th>Passengers</th>
<th>$\delta_f$</th>
<th>$C_{L}$</th>
<th>$C_{M}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>$0^\circ$</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>36</td>
<td>$20^\circ$</td>
<td>0.82</td>
<td>-0.349</td>
</tr>
<tr>
<td>50</td>
<td>$30^\circ$</td>
<td>0.94</td>
<td>-0.387</td>
</tr>
<tr>
<td>75</td>
<td>$20^\circ$</td>
<td>0.94</td>
<td>-0.250</td>
</tr>
<tr>
<td>100</td>
<td>$30^\circ$</td>
<td>1.08</td>
<td>-0.280</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Passengers</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 pax</td>
<td>$C_L = 0.17 + 0.097\alpha + 0.007\delta_E$</td>
</tr>
<tr>
<td>Approach</td>
<td>$C_L = 0.17 + 0.099\alpha + 0.008\delta_E$ (no flaps)</td>
</tr>
<tr>
<td>36 pax</td>
<td>$C_L = 0.17 + 0.097\alpha + 0.007\delta_E$</td>
</tr>
<tr>
<td>Approach</td>
<td>$C_L = 0.17 + 0.099\alpha + 0.008\delta_E + 0.83$ (flaps 20°)</td>
</tr>
<tr>
<td>50 pax</td>
<td>$C_L = 0.17 + 0.097\alpha + 0.007\delta_E$</td>
</tr>
<tr>
<td>Approach</td>
<td>$C_L = 0.17 + 0.099\alpha + 0.008\delta_E + 0.94$ (flaps 30°)</td>
</tr>
<tr>
<td>75 pax</td>
<td>$C_L = 0.17 + 0.114\alpha + 0.016\delta_E$</td>
</tr>
<tr>
<td>Approach</td>
<td>$C_L = 0.17 + 0.115\alpha + 0.016\delta_E + 0.94$ (flaps 20°)</td>
</tr>
<tr>
<td>100 pax</td>
<td>$C_L = 0.17 + 0.114\alpha + 0.016\delta_E$</td>
</tr>
<tr>
<td>Approach</td>
<td>$C_L = 0.17 + 0.115\alpha + 0.016\delta_E + 1.08$ (flaps 30°)</td>
</tr>
</tbody>
</table>

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 \( C_{M_0} \) 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

<table>
<thead>
<tr>
<th>Airplane</th>
<th>( \Delta C_{L_0} )</th>
<th>( \Delta C_{M} )</th>
<th>fwd C.G.</th>
<th>aft C.G.</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 passenger</td>
<td>-0.034</td>
<td>0.138</td>
<td>0.133</td>
<td></td>
</tr>
<tr>
<td>36 passenger</td>
<td>-0.034</td>
<td>0.154</td>
<td>0.150</td>
<td></td>
</tr>
<tr>
<td>50 passenger</td>
<td>-0.034</td>
<td>0.190</td>
<td>0.187</td>
<td></td>
</tr>
<tr>
<td>75 passenger</td>
<td>-0.017</td>
<td>0.064</td>
<td>0.061</td>
<td></td>
</tr>
<tr>
<td>100 passenger</td>
<td>-0.017</td>
<td>0.074</td>
<td>0.071</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.4 - Trimmed Elevator Deflections for the Commuter Family

<table>
<thead>
<tr>
<th>Airplane</th>
<th>Elevator Deflection (deg)</th>
<th>Cruise</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>fwd C.G.</td>
<td>aft C.G.</td>
<td>fwd C.G.</td>
</tr>
<tr>
<td>25 passenger</td>
<td>-2.77°</td>
<td>-3.56°</td>
<td>5.75°</td>
</tr>
<tr>
<td>36 passenger</td>
<td>-2.70°</td>
<td>-3.66°</td>
<td>17.73°</td>
</tr>
<tr>
<td>50 passenger</td>
<td>-3.94°</td>
<td>-4.71°</td>
<td>14.92°</td>
</tr>
<tr>
<td>75 passenger</td>
<td>-0.84°</td>
<td>-1.05°</td>
<td>13.65°</td>
</tr>
<tr>
<td>100 passenger</td>
<td>0.22°</td>
<td>-0.93°</td>
<td>15.58°</td>
</tr>
</tbody>
</table>

*Cruise Thrust **Full Power, Flaps Down
Table 4.5 - Pitching Moment Equations for the Commuter Family

<table>
<thead>
<tr>
<th>Passengers</th>
<th>Cruise, fwd</th>
<th>Cruise, aft</th>
<th>Approach, fwd</th>
<th>Approach, aft</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 pax:</td>
<td>$C_M = 0.124 - 0.224C_L - 0.028E - 0.003(T)$</td>
<td>$C_M = 0.119 - 0.089C_L - 0.028E - 0.003(T)$</td>
<td>$C_M = 0.134 - 0.231C_L - 0.029E - 0.112(T)$</td>
<td>$C_M = 0.129 - 0.096C_L - 0.029E - 0.112(T)$</td>
</tr>
<tr>
<td>36 pax:</td>
<td>$C_M = 0.148 - 0.253C_L - 0.031E - 0.004(T)$</td>
<td>$C_M = 0.144 - 0.119C_L - 0.031E - 0.004(T)$</td>
<td>$C_M = 0.159 - 0.260C_L - 0.032E - 0.349(f) - 0.117(T)$</td>
<td>$C_M = 0.155 - 0.126C_L - 0.032E - 0.349(f) - 0.117(T)$</td>
</tr>
<tr>
<td>50 pax:</td>
<td>$C_M = 0.207 - 0.134C_L - 0.039E - 0.008(T)$</td>
<td>$C_M = 0.204 - 0.061C_L - 0.039E - 0.008(T)$</td>
<td>$C_M = 0.218 - 0.143C_L - 0.041E - 0.387(f) - 0.239(T)$</td>
<td>$C_M = 0.215 - 0.070C_L - 0.041E - 0.387(f) - 0.239(T)$</td>
</tr>
<tr>
<td>75 pax:</td>
<td>$C_M = 0.087 - 0.114C_L - 0.056E - 0.008(T)$</td>
<td>$C_M = 0.087 - 0.114C_L - 0.056E - 0.008(T)$</td>
<td>$C_M = 0.096 - 0.211C_L - 0.056E - 0.250(f) - 0.361(T)$</td>
<td>$C_M = 0.096 - 0.044C_L - 0.056E - 0.250(f) - 0.361(T)$</td>
</tr>
<tr>
<td>100 pax:</td>
<td>$C_M = 0.107 - 0.332C_L - 0.064E - 0.010(T)$</td>
<td>$C_M = 0.107 - 0.189C_L - 0.064E - 0.010(T)$</td>
<td>$C_M = 0.116 - 0.323C_L - 0.064E - 0.280(f) - 0.379(T)$</td>
<td>$C_M = 0.116 - 0.180C_L - 0.064E - 0.280(f) - 0.379(T)$</td>
</tr>
</tbody>
</table>
Figure 4.1
Wing maximum lift at low speed
Figure 4.2
Wing Maximum Lift at Cruise
FIGURE 4.3
25, 36, 50 PASSENGER WING LIFT CURVE

WING ANGLE OF ATTACK, ° DEG
Figure 4.14
75,100 Passenger Wing Lift Curve
Figure 4.6
25 PASSENGER AIRPLANE
APPROACH PITCH TRIM DIAGRAM

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Figure 4.7

36 PASSENGER AIRPLANE
CRUISE PITCH-TRIM DIAGRAM

UNIVERSITY OF KANSAS
Figure 4.9

36 PASSENGER - APPROACH
FLAPS DOWN/PITCH-TRIM DIAGRAM

UNIVERSITY OF KANSAS
50 PASSENGER - APPROACH
FLAPS DOWN PITCH TRIM DIAGRAM
Figure 4.13
75 Passenger Airplane
Cruise Pitch-Trim Diagram
Figure 4.15

75 PASSENGER - APPROACH
FLAPS DOWN PITCH TRIM DIAGRAM

UNIVERSITY OF KANSAS
Figure 4.17

100 PASSENGER - APPROACH
FLAPS DOWN PITCH TRIM DIAGRAM
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 \( \omega_{D} x \xi_{D} \) at forward C.G.

Table 4.6 - Handling Qualities for the Commuter Family

<table>
<thead>
<tr>
<th>Airplane</th>
<th>Flight Condition</th>
<th>( \omega_{sp} )</th>
<th>( \xi_{sp} )</th>
<th>( \omega_{D} )</th>
<th>( \xi_{D} )</th>
<th>( \omega_{D} x \xi_{D} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 pax</td>
<td>fwd C.G. - Cruise</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>aft C.G. - Cruise</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>fwd C.G. - Approach</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>aft C.G. - Approach</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>36 pax</td>
<td>fwd C.G. - Cruise</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>aft C.G. - Cruise</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>fwd C.G. - Approach</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>aft C.G. - Approach</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>50 pax</td>
<td>fwd C.G. - Cruise</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>aft C.G. - Cruise</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>fwd C.G. - Approach</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>aft C.G. - Approach</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>75 pax</td>
<td>fwd C.G. - Cruise</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>aft C.G. - Cruise</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>fwd C.G. - Approach</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>aft C.G. - Approach</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>100 pax</td>
<td>fwd C.G. - Cruise</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>aft C.G. - Cruise</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>fwd C.G. - Approach</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>aft C.G. - Approach</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
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 satisfy take-off rotation requirements.

Table 4.6 - Take-off Rotation Requirements

<table>
<thead>
<tr>
<th>Airplane</th>
<th>Total T-O Thrust</th>
<th>Required $\delta_R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 passenger</td>
<td>13,325 lbs</td>
<td>23.1 deg</td>
</tr>
<tr>
<td>36 passenger</td>
<td>15,481 lbs</td>
<td>22.9 deg</td>
</tr>
<tr>
<td>50 passenger</td>
<td>18,929 lbs</td>
<td>20.5 deg</td>
</tr>
<tr>
<td>75 passenger</td>
<td>37,891 lbs</td>
<td>28.1 deg</td>
</tr>
<tr>
<td>100 passenger</td>
<td>37,891 lbs</td>
<td>22.4 deg</td>
</tr>
</tbody>
</table>

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 listed in Table 4.7.

Table 4.7 - Engine-out Requirements

<table>
<thead>
<tr>
<th>Airplane</th>
<th>Total T-O Thrust</th>
<th>Required $\delta_R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 passenger</td>
<td>13,325 lbs</td>
<td>23.1 deg</td>
</tr>
<tr>
<td>36 passenger</td>
<td>15,481 lbs</td>
<td>22.9 deg</td>
</tr>
<tr>
<td>50 passenger</td>
<td>18,929 lbs</td>
<td>20.5 deg</td>
</tr>
<tr>
<td>75 passenger</td>
<td>37,891 lbs</td>
<td>28.1 deg</td>
</tr>
<tr>
<td>100 passenger</td>
<td>37,891 lbs</td>
<td>22.4 deg</td>
</tr>
</tbody>
</table>
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 separate surface aileron could be used to achieve this. Separate 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

<table>
<thead>
<tr>
<th>Model</th>
<th>25 pax</th>
<th>36 pax</th>
<th>50 pax</th>
<th>75 pax</th>
<th>100 pax</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{1p}$</td>
<td>-.715</td>
<td>-.715</td>
<td>-.715</td>
<td>-.792</td>
<td>-.792</td>
</tr>
<tr>
<td>$C_{1A}$</td>
<td>.553</td>
<td>.553</td>
<td>.553</td>
<td>.608</td>
<td>.608</td>
</tr>
<tr>
<td>$\delta^*$</td>
<td>.22</td>
<td>.27</td>
<td>.30</td>
<td>.53</td>
<td>.65</td>
</tr>
<tr>
<td>$T_{R_{\text{CR}}}$</td>
<td>.34</td>
<td>.41</td>
<td>.47</td>
<td>.84</td>
<td>1.02</td>
</tr>
<tr>
<td>$T_{R_{\text{VMC}}}$</td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>$T_{R_{\text{REQ}}}$</td>
<td>107°</td>
<td>104°</td>
<td>102°</td>
<td>56°</td>
<td>52°</td>
</tr>
<tr>
<td>$\delta^*$</td>
<td>5°</td>
<td>5°</td>
<td>5°</td>
<td>5°</td>
<td>5°</td>
</tr>
<tr>
<td>$\delta^*$</td>
<td>56°</td>
<td>53°</td>
<td>52°</td>
<td>35°</td>
<td>31°</td>
</tr>
<tr>
<td>$\delta^*$</td>
<td>10°</td>
<td>10°</td>
<td>10°</td>
<td>10°</td>
<td>10°</td>
</tr>
</tbody>
</table>

$\delta^*_{\text{CR}}$ = Roll angle in 1.9 seconds, must be at least 45°

$\delta^*_{\text{VMC}}$ = 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:

$$ P = L \cdot \delta_A \cdot e^P \cdot \delta_A $$

and

$$ a_y = P \cdot l $$

where \( l \) = Distance from airplane centerline to fuselage centerline.

The following table summarizes the accelerations for the twinbody models.

<table>
<thead>
<tr>
<th>Table 4.9 - Lateral Accelerations For the Twinbody Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>75 pax</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>( P_{CR} ) (rad/sec(^2))</td>
</tr>
<tr>
<td>( P_{VMC} ) (rad/sec(^2))</td>
</tr>
<tr>
<td>( l ) (ft)</td>
</tr>
<tr>
<td>( a_{yCR} ) (ft/sec(^2))</td>
</tr>
<tr>
<td>( a_{yVMC} ) (ft/sec(^2))</td>
</tr>
<tr>
<td>( a_{yCR} ) ( g )</td>
</tr>
<tr>
<td>( a_{yVMC} ) ( g )</td>
</tr>
</tbody>
</table>

The accelerations at the aft loading conditions (highest \( I_{xx} \)) 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 similar 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 similar for each airplane in the family.

Commonality will be attempted by using a programmable control loader. This system can augment 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>
<thead>
<tr>
<th>Table 5.1 - Elevator Hinge Moments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
</tr>
<tr>
<td>c_f/c</td>
</tr>
<tr>
<td>S_E</td>
</tr>
<tr>
<td>c_f</td>
</tr>
<tr>
<td>C_h_a</td>
</tr>
<tr>
<td>C_h_6_e</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 5.2 - Rudder Hinge Moments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
</tr>
<tr>
<td>c_f/c</td>
</tr>
<tr>
<td>S_R</td>
</tr>
<tr>
<td>c_f</td>
</tr>
<tr>
<td>C_h_a</td>
</tr>
<tr>
<td>C_h_6_r</td>
</tr>
</tbody>
</table>
Table 5.3 - Aileron Hinge Moments

<table>
<thead>
<tr>
<th>Model</th>
<th>25 pax</th>
<th>36 pax</th>
<th>50 pax</th>
<th>75 pax</th>
<th>100 pax</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c_f/c$</td>
<td>.30</td>
<td>.30</td>
<td>.30</td>
<td>.30</td>
<td>.30</td>
</tr>
<tr>
<td>$S_A$</td>
<td>12 ft$^2$</td>
<td>12 ft$^2$</td>
<td>12 ft$^2$</td>
<td>12 ft$^2$</td>
<td>12 ft$^2$</td>
</tr>
<tr>
<td>$c_f$</td>
<td>2.00 ft</td>
<td>2.00 ft</td>
<td>2.00 ft</td>
<td>2.00 ft</td>
<td>2.00 ft</td>
</tr>
<tr>
<td>$C_{ha}$</td>
<td>-.042</td>
<td>-.042</td>
<td>-.042</td>
<td>-.036</td>
<td>-.036</td>
</tr>
<tr>
<td>$C_{h_A}$</td>
<td>-.073</td>
<td>-.073</td>
<td>-.073</td>
<td>-.094</td>
<td>-.094</td>
</tr>
</tbody>
</table>

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) $V = 207.5$ fps, sea level, 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 $-0.167$ 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

<table>
<thead>
<tr>
<th>Model</th>
<th>$V_{mc}$ fwd C.G.</th>
<th>$V_{mc}$ aft C.G.</th>
<th>CR fwd C.G.</th>
<th>CR aft C.G.</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 pax</td>
<td>44</td>
<td>3</td>
<td>176</td>
<td>169</td>
</tr>
<tr>
<td>36 pax</td>
<td>1</td>
<td>-38</td>
<td>16</td>
<td>-1</td>
</tr>
<tr>
<td>50 pax</td>
<td>-48</td>
<td>-48</td>
<td>-72</td>
<td>-49</td>
</tr>
<tr>
<td>75 pax</td>
<td>-170</td>
<td>-570</td>
<td>-570</td>
<td>-2675</td>
</tr>
<tr>
<td>100 pax</td>
<td>-126</td>
<td>-201</td>
<td>-567</td>
<td>-573</td>
</tr>
</tbody>
</table>

Stick forces in lbs
Table 5.5 - Longitudinal Stick Force per G

<table>
<thead>
<tr>
<th>Model</th>
<th>V_m</th>
<th>fwd C.G.</th>
<th>V_m</th>
<th>aft C.G.</th>
<th>CR fwd C.G.</th>
<th>CR aft C.G.</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 pax</td>
<td>65</td>
<td>13</td>
<td>69</td>
<td>-6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36 pax</td>
<td>47</td>
<td>-1</td>
<td>45</td>
<td>-27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 pax</td>
<td>18</td>
<td>3</td>
<td>-11</td>
<td>-32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75 pax</td>
<td>152</td>
<td>818</td>
<td>28</td>
<td>426</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 pax</td>
<td>203</td>
<td>65</td>
<td>173</td>
<td>-20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Gradient in lbs/G

Table 5.6 - Longitudinal Stick Force per Knot Gradient

<table>
<thead>
<tr>
<th>Model</th>
<th>V_m</th>
<th>fwd C.G.</th>
<th>V_m</th>
<th>aft C.G.</th>
<th>CR fwd C.G.</th>
<th>CR aft C.G.</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 pax</td>
<td>.08</td>
<td>.18</td>
<td>.23</td>
<td>.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36 pax</td>
<td>-.06</td>
<td>.02</td>
<td>-.02</td>
<td>.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 pax</td>
<td>-.07</td>
<td>-.03</td>
<td>-.06</td>
<td>.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75 pax</td>
<td>-1.09</td>
<td>-5.25</td>
<td>-1.42</td>
<td>-7.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 pax</td>
<td>-1.07</td>
<td>-.85</td>
<td>-1.76</td>
<td>-1.38</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Model</th>
<th>V_m</th>
<th>Cruise</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 pax</td>
<td>177</td>
<td>166</td>
</tr>
<tr>
<td>36 pax</td>
<td>308</td>
<td>910</td>
</tr>
<tr>
<td>50 pax</td>
<td>383</td>
<td>1238</td>
</tr>
<tr>
<td>75 pax</td>
<td>319</td>
<td>538</td>
</tr>
<tr>
<td>100 pax</td>
<td>479</td>
<td>1248</td>
</tr>
</tbody>
</table>

Pedal forces in lbs.
Table 5.8 - Rudder Pedal Gradient

<table>
<thead>
<tr>
<th>Model</th>
<th>$V_{mc}$</th>
<th>Cruise</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 pax</td>
<td>35</td>
<td>55</td>
</tr>
<tr>
<td>36 pax</td>
<td>62</td>
<td>303</td>
</tr>
<tr>
<td>50 pax</td>
<td>76</td>
<td>413</td>
</tr>
<tr>
<td>75 pax</td>
<td>64</td>
<td>179</td>
</tr>
<tr>
<td>100 pax</td>
<td>96</td>
<td>416</td>
</tr>
</tbody>
</table>

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 similar 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

<table>
<thead>
<tr>
<th>Model</th>
<th>$V_{mc}$</th>
<th>Cruise</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 pax</td>
<td>-4.0</td>
<td>-6.0</td>
</tr>
<tr>
<td>36 pax</td>
<td>-4.0</td>
<td>-6.0</td>
</tr>
<tr>
<td>50 pax</td>
<td>-4.0</td>
<td>-6.0</td>
</tr>
<tr>
<td>75 pax</td>
<td>-4.6</td>
<td>-6.8</td>
</tr>
<tr>
<td>100 pax</td>
<td>-4.6</td>
<td>-6.8</td>
</tr>
</tbody>
</table>

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 requirements, 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 meet 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 separately for the different airplanes (25, 36, 50, 75 and 100 passenger airplanes).

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

\[ C_D = C_{D_{\text{wing}}} + C_{D_{\text{fus}}} + C_{D_{\text{emp}}} + C_{D_{\text{np}}} + C_{D_{\text{flaps}}} + C_{D_{\text{gear}}} + C_{D_{\text{cw}}}. \]

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 \( C_{D_{\text{cw}}} \) 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 \( C_{D_{n_{\text{int}}}} \) 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

<table>
<thead>
<tr>
<th>Airplane L/D&lt;sub&gt;max&lt;/sub&gt;</th>
<th>Cruise</th>
<th>Low Speed (0° flaps) (gear down)</th>
<th>Low Speed (30° flaps) (gear down)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>24.4</td>
<td>.0129 + .0309 C&lt;sub&gt;L&lt;/sub&gt;&lt;sup&gt;2&lt;/sup&gt;</td>
<td>.1242 + .0308 C&lt;sub&gt;L&lt;/sub&gt;&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>36</td>
<td>22.4</td>
<td>.0160 + .0309 C&lt;sub&gt;L&lt;/sub&gt;&lt;sup&gt;2&lt;/sup&gt;</td>
<td>.1319 + .0308 C&lt;sub&gt;L&lt;/sub&gt;&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>50</td>
<td>22.6</td>
<td>.0156 + .0309 C&lt;sub&gt;L&lt;/sub&gt;&lt;sup&gt;2&lt;/sup&gt;</td>
<td>.1658 + .0308 C&lt;sub&gt;L&lt;/sub&gt;&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>75</td>
<td>26.6</td>
<td>.0139 + .0253 C&lt;sub&gt;L&lt;/sub&gt;&lt;sup&gt;2&lt;/sup&gt;</td>
<td>.1564 + .0240 C&lt;sub&gt;L&lt;/sub&gt;&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>100</td>
<td>26.2</td>
<td>.0145 + .0253 C&lt;sub&gt;L&lt;/sub&gt;&lt;sup&gt;2&lt;/sup&gt;</td>
<td>.1857 + .0240 C&lt;sub&gt;L&lt;/sub&gt;&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

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
Figure 6.1 25 Passenger Cruise Drag Polar
Figure 6.2 36 Passenger Cruise Drag Polar
Figure 6.3 50 Passenger Cruise Drag Polar

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Figure 6.4 75 Passenger Cruise Drag Polar
Figure 6.6 25 Passenger Approach Drag Polar
Figure 6.7 36 Passenger Approach Drag Polar
Figure 6.8  50 Passenger Approach Drag Polar

UNIVERSITY OF KANSAS
Figure 6.9 75 Passenger Approach Drag Polar
Figure 6.10 100 Passenger Approach Drag Polar
7.0 VERIFICATION OF MISSION PERFORMANCE

The purpose of this section is to verify the mission performance objectives 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 spreadsheet 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
   \[ V = 250 \text{ kts} \]
   \[ h = 10,000 \text{ ft} \]
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>
<thead>
<tr>
<th>Model</th>
<th>Required</th>
<th>TOFL</th>
<th>LFL</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>3500 ft</td>
<td>3325 ft</td>
<td>3365 ft</td>
</tr>
<tr>
<td>36</td>
<td>3500 ft</td>
<td>3414 ft</td>
<td>3467 ft</td>
</tr>
<tr>
<td>50</td>
<td>3500 ft</td>
<td>3403 ft</td>
<td>3468 ft</td>
</tr>
<tr>
<td>75</td>
<td>3500 ft</td>
<td>3484 ft</td>
<td>3337 ft</td>
</tr>
<tr>
<td>100</td>
<td>3500 ft</td>
<td>3465 ft</td>
<td>3370 ft</td>
</tr>
</tbody>
</table>

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):

\[ R.C. = \left( \frac{T_{AV}}{W} - C_D/C_L \right) \times \left( \frac{2W/\rho C_L S}{2W/\rho C_L S} \right)^{0.5} \]

Climb Gradient = \( \frac{R.C.}{U_1} \)

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

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

Table 7.3

Actual Climb Gradients for the Commuter Family

<table>
<thead>
<tr>
<th>Climb Reqmt. #</th>
<th>25</th>
<th>36</th>
<th>50</th>
<th>75</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.79</td>
<td>11.10</td>
<td>10.04</td>
<td>13.77</td>
<td>12.93</td>
</tr>
<tr>
<td>2</td>
<td>5.86</td>
<td>6.99</td>
<td>6.52</td>
<td>4.76</td>
<td>4.96</td>
</tr>
<tr>
<td>3</td>
<td>10.79</td>
<td>11.10</td>
<td>10.04</td>
<td>13.77</td>
<td>12.93</td>
</tr>
<tr>
<td>4</td>
<td>9.92</td>
<td>11.20</td>
<td>13.24</td>
<td>11.02</td>
<td>12.83</td>
</tr>
<tr>
<td>5</td>
<td>26.70</td>
<td>26.65</td>
<td>23.71</td>
<td>23.30</td>
<td>22.01</td>
</tr>
<tr>
<td>6</td>
<td>5.20</td>
<td>5.24</td>
<td>3.24</td>
<td>3.78</td>
<td>2.76</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Model</th>
<th>Sea Level</th>
<th>10,000 ft</th>
<th>30,000 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>3138</td>
<td>4693</td>
<td>984</td>
</tr>
<tr>
<td>36</td>
<td>3053</td>
<td>4128</td>
<td>573</td>
</tr>
<tr>
<td>50</td>
<td>3064</td>
<td>4433</td>
<td>1224</td>
</tr>
<tr>
<td>75</td>
<td>3753</td>
<td>5763</td>
<td>2150</td>
</tr>
<tr>
<td>100</td>
<td>2534</td>
<td>4684</td>
<td>1568</td>
</tr>
</tbody>
</table>

Rate of Climb in fpm
Figure 7.2 Payload Range Diagrams

A - Range w/ Max Wpl
B - Range w/ Max Wf
C - Ferry Range

Payload Weight / Wpl Lbs x 10^3

100 Pax

75 Pax

50 Pax

36 Pax

25 Pax

Range, R Miles x 10^-3

0 1 2 3 4 5 6
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.
7. Common powerplants.
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 6.1--Status of Commonality in the Commuter Family.

<table>
<thead>
<tr>
<th>Type</th>
<th>Airplane</th>
<th>25 Pax</th>
<th>36 Pax</th>
<th>50 Pax</th>
<th>75 Pax</th>
<th>100 Pax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural Commonality:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tailcone Arrangement</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Wing Design</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fuselage Cross Section</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Landing Gear</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Systems Commonality:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cockpit Instrum.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Dynamic Handling Qualities</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Stick Forces and Gradients</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Fuel System</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>De-Icing</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Pressurization</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Flight Controls</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Engine Commonality:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Engines</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>5500 shp</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>11,000 shp</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
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.
### Table 8.2a

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

### 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 |
| $\Delta W_{TO}$ | 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.

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

### Table 8.3b—Comparison of Acquisition Costs.

<table>
<thead>
<tr>
<th>Airplane Initial Prod. (incl. DT&amp;E)</th>
<th>Production Baselines</th>
<th>Commonality Implemented</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 Pax</td>
<td>8667362</td>
<td>7363869</td>
</tr>
<tr>
<td>36 Pax</td>
<td>9490391</td>
<td>7948048</td>
</tr>
<tr>
<td>50 Pax</td>
<td>10428089</td>
<td>8611920</td>
</tr>
<tr>
<td>75 Pax</td>
<td>15682836</td>
<td>13069259</td>
</tr>
<tr>
<td>100 Pax</td>
<td>17121109</td>
<td>14079259</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>AIRPLANE MODEL</th>
<th>RANGE OF C.G. TRAVEL</th>
<th>COMMON EXCURSION RANGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 passenger</td>
<td>12&quot; .13c</td>
<td>12&quot;-20&quot; .14 - .27 c</td>
</tr>
<tr>
<td>36 passenger</td>
<td>12&quot; .13c</td>
<td>12&quot;-20&quot; .14 - .27 c</td>
</tr>
<tr>
<td>50 passenger</td>
<td>6&quot; .09c</td>
<td>12&quot;-20&quot; .14 - .27 c</td>
</tr>
<tr>
<td>75 passenger</td>
<td>18&quot; .17c</td>
<td>12&quot;-20&quot; .14 - .27 c</td>
</tr>
<tr>
<td>100 passenger</td>
<td>15&quot; .14c</td>
<td>12&quot;-20&quot; .14 - .27 c</td>
</tr>
</tbody>
</table>

### Table 9.2 WING LOADINGS OF EXISTING AIRPLANES

<table>
<thead>
<tr>
<th>Airplane</th>
<th>Pax</th>
<th>(W/S) T0</th>
<th>psf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beech 1900</td>
<td>19</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>DHC-6-300</td>
<td>20</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>BAe 31</td>
<td>18</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>METRO III</td>
<td>19</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>CASA C-212-200</td>
<td>28</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>DHC-8</td>
<td>37</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>EMB-120</td>
<td>30</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>Shorts 330</td>
<td>30</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>Fokker F27-200</td>
<td>52</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>DHC-7</td>
<td>50</td>
<td>67</td>
<td></td>
</tr>
<tr>
<td>Fokker F-28</td>
<td>85</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>BAe 146-200</td>
<td>100</td>
<td>108</td>
<td></td>
</tr>
</tbody>
</table>

### Table 9.3 WING LOADINGS FOR THE COMMUTER FAMILY

<table>
<thead>
<tr>
<th>Airplane Model</th>
<th>(W/S) T0</th>
<th>psf</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 Passenger</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>36 Passenger</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>50 Passenger</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>75 Passenger</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>100 Passenger</td>
<td>72</td>
<td></td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Airplane Type</th>
<th>Number of Passengers</th>
<th>Overhead Volume (cuft)</th>
<th>Overhead Volume per Seat (cuft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50, 100</td>
<td>50</td>
<td>56</td>
<td>1.1</td>
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<tr>
<td>36, 75</td>
<td>36</td>
<td>41</td>
<td>1.1</td>
</tr>
<tr>
<td>25</td>
<td>25</td>
<td>29</td>
<td>1.2</td>
</tr>
<tr>
<td>British Aerospace</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAe Super 748</td>
<td>46</td>
<td>41</td>
<td>0.85</td>
</tr>
<tr>
<td>BAe ATP</td>
<td>48</td>
<td>100</td>
<td>1.6</td>
</tr>
<tr>
<td>BAe 146-100</td>
<td>64</td>
<td>56</td>
<td>0.68</td>
</tr>
<tr>
<td>de Havilland</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DASH 7</td>
<td>50</td>
<td>59</td>
<td>1.2</td>
</tr>
<tr>
<td>DASH 8</td>
<td>37</td>
<td>32</td>
<td>0.86</td>
</tr>
<tr>
<td>Fokker</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F-27</td>
<td>52</td>
<td>40</td>
<td>0.77</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>79</td>
<td>1.6</td>
</tr>
<tr>
<td>F-28</td>
<td>65</td>
<td>107</td>
<td>1.6</td>
</tr>
<tr>
<td>Shorts</td>
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<tr>
<td>330</td>
<td>30</td>
<td>40</td>
<td>1.3</td>
</tr>
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<td>360</td>
<td>36</td>
<td>52</td>
<td>1.4</td>
</tr>
<tr>
<td>ATR Consortium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATR 42-200</td>
<td>46</td>
<td>53</td>
<td>1.2</td>
</tr>
<tr>
<td>Embraer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EMB-120</td>
<td>30</td>
<td>32</td>
<td>1.1</td>
</tr>
</tbody>
</table>
Figure 9.1 Weight Trends for Regional Turbo-Propeller Driven Airplanes

Copied from: Roskam, Airplane Design Part I
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 family of commuter airplanes have been designed. These airplanes range from 25 to 100 passengers.

3) Takeoff 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 occurred (12% on the 25 passenger airplane).

7) Cost savings of about $1.3 million per airplane have occurred 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 79O Design Team; Class I Designs of a Family of Commuter Airplanes; University of Kansas, 1986.


3) University of Kansas AE 79O Design Team; A Class II Weight Assessment for the Implementation of Commonality and Preliminary Structural Designs for the Family of Commuter Airplanes; University of Kansas, 1987.

4) Russell, M., and Haddad, R., University of Kansas AE 79O Design Team; Presentation of Structural Component Designs for the Family of Commuter Airplanes; University of Kansas, 1987.

5) Swift, G., University of Kansas AE 79O Design Team; Advanced Propfan Analysis for the Family of Commuter Airplanes; University of Kansas, May 1987.


APPENDIX A

COCKPIT AND FUSELAGE ARRANGEMENTS
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
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</thead>
<tbody>
<tr>
<td>A.1 FUSELAGE CROSS SECTION</td>
<td>A.3</td>
</tr>
<tr>
<td>A.1.1 Determination of Overhead Baggage Volume</td>
<td>A.5</td>
</tr>
<tr>
<td>A.2 COCKPIT LAYOUT</td>
<td>A.10</td>
</tr>
<tr>
<td>A.3 CABIN LAYOUTS</td>
<td>A.11</td>
</tr>
</tbody>
</table>
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.
A.1.1 DETERMINATION OF OVERHEAD BAGGAGE VOLUME
OVERHEAD VOLUME

\[ \text{Area of sector} = \frac{1}{2} r^2 \theta \quad (\theta \text{ in radians}) \]
\[ = \frac{1}{2} (2.26)^2 (39.5') \left( \frac{\pi}{180} \right) \]
\[ = 1.76 \text{ in}^2 \]
**Area of Triangle A:**

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

**Area of Triangle B:**

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

**Area of Triangle C:**

\[ A = \frac{1}{2}bh = \frac{1}{2} \times (2.26 \times 0.22) = 0.32 \text{ in}^2 \]

Original page is of poor quality.
The Area of Overhead Storage is calculated as follows:

\[ A = (1.76 \text{ in}^2) - (0.25 \text{ in}^2) - (0.90 \text{ in}^2) - (0.32 \text{ in}^2) \]

\[ A = 0.29 \text{ in}^2 \]

\[ A = 116 \text{ in}^2 = 0.81 \text{ ft}^2 \]

The 50 Passenger Overhead Volume is:

\[ V = (0.81 \text{ ft}^2)(9.5 \text{ in})(50 \text{ in/ft}) + (0.81 \text{ ft}^2)(8 \text{ in})(50 \text{ in/ft}) \]

\[ V = (12 \text{ in/ft}) \]

\[ \text{Volume} = 56 \text{ ft}^3 \]

The 36 Passenger Overhead Volume is:

\[ V = (0.81 \text{ ft}^2)(6.1 \text{ in})(50 \text{ in/ft})(2 \text{ rows}) \]

\[ V = (12 \text{ in/ft}) \]

\[ V = 41 \text{ ft}^3 \]

The 25 Passenger Overhead Volume is:

\[ V = (0.81 \text{ ft}^2)(4.3 \text{ in})(50 \text{ in/ft})(2 \text{ rows}) \]

\[ V = (12 \text{ in/ft}) \]

\[ V = 29 \text{ ft}^3 \]

**Figure A.1** lists the overhead volume per passenger of the 25, 36 and 50 passenger commuter's along with the values for other commuter airplanes for comparison.
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<th>Overhead Volume per Seat (cuft)</th>
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<td>25</td>
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<td>59</td>
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<td>50</td>
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<td>F-28</td>
<td>65</td>
<td>107</td>
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<td>40</td>
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<td>360</td>
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<td>52</td>
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<td>46</td>
<td>53</td>
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</table>
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 accommodate 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 EICAS
- 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 Management 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.
FIGURE A.2: 25 PASSENGER CABIN LAYOUT

SCALE: 1:50 INCHES
Appendix B
Airplane component weight, center of gravity and inertia breakdowns.
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<th>Item</th>
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<th>Nom. Arw</th>
<th>Moment</th>
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<th>l-xx (Mto)</th>
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**Weights:**
- Fuselage: 584,679
- Wing: 1,202,585
- Vertical Tail: 30,269
- Horizontal Tail: 37,787
- Engine Mount: 3,466
- Engines: 103,545
- Furnishings: 28,156
- Fuel: 1,562,635
- Passengers: 165,250

**Products:**
- 81,472
- 4,474
- 1,071,609
- 1,165,212
- 672,140
- 227,091
- 246,949
- 1,318,763
- 1,525,859
- 171,958
- 7,434
- 10,635
- 6,202
- 291,733
- 9,715
- 2,495,797
- 78,090
- 171,566
- 579,533
- 120,024
- 24,847
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- 0
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- 17,507,196
- 18,993,010
Airplane inertias:

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Weight Used  | 19,614 | 28,506 |
C.G. Location | 578    | 571    |
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36 Passenger Airplane

Summary of Inertias:
(slug-ft²)
### Airplane

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- Fuel: 5,046,415
- Passengers: 7,096,415
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50 Passenger Airplane
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Airframe: 1-xx 1-yy 1-zz
- Fuselage: 2,859,997 9,403,601 9,403,601
- Outbd. Wing: 1,206,585 76,147 1,276,659
- Center Wing: 1,235,690 64,319 1,316,342
- 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 2,761,026 3,230,599
- Outbd. Fuel: 2,867,702 25,362 2,994,342
- Center Fuel: 5,926,229 304,956 6,232,866
- Passengers: 425,039 15,569,677 15,824,573
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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
25 Passenger Airplane: Calculations for Cruise and M.C. at Fwd and Aft C.G.

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<tr>
<th>Cruise Mach Number</th>
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<td>Min Control Dynamic Pres.</td>
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<td>Cruise A.C.</td>
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<td>Min Ctrl A.C.</td>
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<td>Fuselage Length</td>
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<td>C-m-o-body</td>
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<table>
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<td>Wing 'Span ft</td>
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<td>Wing M.EC ft</td>
</tr>
<tr>
<td>Aspect Ratio</td>
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<tr>
<td>Leading Edge Sweep rad</td>
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<td>Semi-chord Sweep rad</td>
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<td>C-m-o-wing (cruise)</td>
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<td>C-m-o-wing (approach)</td>
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<td>H.T. Area (each) sqft</td>
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<td>H.T. Span ft</td>
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<td>H.T. Root Chord</td>
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<td>H.T. M.EC ft</td>
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<td>H.T. Aspect Ratio</td>
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<td>H.T. c/2 Sweep rad</td>
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<td>H.T. Taper Ratio</td>
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<td>H.T. X-ac-h bar</td>
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<td>H.T. q-bar corr. (eta-h)</td>
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<td>Elevator effectiveness re</td>
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<td>V.T. Area (each) sqft</td>
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<td>V.T. Span ft</td>
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<td>V.T. Aspect Ratio</td>
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<td>k:0.6820 C-L-e (app)</td>
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<td>k:0.6820 C-L-e (app)</td>
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<td>k:0.68 C-L-e (app)</td>
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<tr>
<td>V.T. LE Sweep (rad)</td>
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<tr>
<td>V.T. c/2 Sweep (rad)</td>
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<td>V.T. Taper Ratio</td>
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<td>V.T. Moment Arm 1-v</td>
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<td>Approach Alpha α (rad)</td>
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<td>Approach V.T. 1-v</td>
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<td>1*(dα/dθ)</td>
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**Engine Mounting Bar:**

| Bar Area sqft          | 112.000  |
| Bar Span ft            | 41.000   |
| Bar NC 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 - domwash            | 1.000    |
| Bar q-bar corr. (eta-h)| 1.000    |

**Total Take-off Thrust lbs** 13,325
**Total Cruise Thrust (lbs)** 1,698
**I-T (vertical mom. arm)** 1.520
**Y-T (horizontal mom. arm)** 10.500

**Non-dim. Derivatives:**

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<th>Min Cntrl-fwd</th>
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<tr>
<td>C-L-e-dot</td>
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<td>C-ws-dot</td>
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**Dimensional Derivatives:**

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**Engine Bar Lift Curves:**

| K11.0202 | C-L-e (cruise) | 1.5317 |
| 0.70       | C-L-e (app)    | 1.5395 |
| 0.10       | 0.71           | 0.71   |
W-θ:  2.760    2.705    1.123    1.101
W-τ: -0.391   -0.383   -0.384   -0.376

Short Period:
Frequency  3.247    2.316    1.792    1.413
Damping Ratio  0.406    0.587    0.603    0.764
N=  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
Ω* ζ*  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
Ω* ζ* yes yes yes yes

Engine-Out Calculations:
C-γ-τ τ  0.324
C-τ-τ  0.085
Required 6-τ (rad)  0.402
Required 6-τ (deg) 23.051

Airplane X-ac (cruise)  0.369
Airplane X-ac (approach)  0.376
Airplane C-l-ac (cruise)  5.579
Airplane C-l-ac (approach)  5.670
Airplane C-M-ac (cruise)
   Forward C.G.  -1.251
   Aft C.G.    -0.498
Airplane C-M-ac (approach)
   Forward C.G.  -1.306
   Aft C.G.    -0.543
C-l-i-H (cruise)  0.778
C-l-i-H (approach)  0.803
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Lift Curve Equations:

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<td>Cruise</td>
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Pitching Moment Equations:

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<td>Wheel-ground friction μ</td>
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### 25 Passenger Airplane: Calculations for Cruise and H.C. at Fwd and Aft C.G.

*Note: All Results in RADIANS*

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<tr>
<th>Parameter</th>
<th>Fwd C.G.</th>
<th>Aft C.G.</th>
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<td>Min Control Dynamic Pres.</td>
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<td>Cruise Dynamic Pressure</td>
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<td>1/rad to 1/deg conversion</td>
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<td>V.T. Effective Asp. Ratio</td>
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### Lift Curves:

- **Wing Lift Curves**
  - **K<sub>1</sub>**: 0.0544 C-L-e (cruise) 4.7089
  - **K<sub>2</sub>**: 0.6820 C-L-e (app) 4.7794

- **Horizontal Tail Lift Curves**
  - **K<sub>1</sub>**: 0.0630 C-L-e (cruise) 3.8395
  - **K<sub>2</sub>**: 0.6820 C-L-e (app) 3.9610

- **Vertical Tail Lift Curves**
  - **K<sub>1</sub>**: 0.0366 C-L-e (cruise) 2.0602
  - **K<sub>2</sub>**: 0.68  C-L-e (app) 2.2314
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<td>V.T. Moment Arm I-v</td>
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**Engine Mounting Bar:**

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**Total Take-off Thrust lbs**

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**Total Cruise Thrust (lbs)**

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**I-T (vertical mom. arm)**

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**Y-T (horizontal mom. arm)**

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**Non-dim. Derivatives:**

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<th>Parameter</th>
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<th>Cruise-aft</th>
<th>Min Cntrl-fwd</th>
<th>Min Cntrl-aft</th>
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</thead>
<tbody>
<tr>
<td>$C_{L-s}$ Airplane</td>
<td>5.579</td>
<td>5.579</td>
<td>5.670</td>
<td>5.670</td>
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<td>$C_{m-s}$ Airplane</td>
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<td>-0.673</td>
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<tr>
<td>$C_{L-s}$-dot</td>
<td>1.570</td>
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<tr>
<td>$C_{m-s}$-dot</td>
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<td>-5.992</td>
<td>-6.432</td>
<td>-6.182</td>
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<tr>
<td>$C_{m-q}$</td>
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<td>$C_{y-o}$</td>
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<td>-1.166</td>
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<td>$C_{n-o}$</td>
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<td>0.045</td>
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<td>$C_{y-r}$</td>
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<td>$C_{n-r}$</td>
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<td>-0.106</td>
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**Dimensional Derivatives:**

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<td>$I_{m-s}$-dot</td>
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<td>$N_{m-s}$</td>
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<td>$N_{m-s}$-dot</td>
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**Engine Bar Lift Curves:**

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<td>C-L-s (cruise) 1.5317</td>
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<td>$k_{10.68}$</td>
<td>C-L-s (app) 1.5395</td>
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<tr>
<td>$k_{10.71}$</td>
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</table>
Short Period:
Frequency 2.976
Damping Ratio 0.409
\( \omega \) 36.306

Dutch Roll:
Frequency 1.634
Damping Ratio 0.166
\( \omega \) 1.054

Verify Class I Handling Qualities:
Short Period:
Below max freq. yes
Above max freq. yes
Damping yes

Dutch Roll:
Frequency yes
Damping yes
\( \omega \) 1.054

Engine-Out Calculations:
C-\( y \)-\( \delta \) -0.324
C-\( n \)-\( \delta \) 0.085
Required \( \delta \) (rad) 0.402
Required \( \delta \) (deg) 23.051

Lift and Pitching Moment Calculations:
Airplane X-ac (cruise) 0.369
Airplane X-ac (approach) 0.376
Airplane C-L-e (cruise) 5.579
Airplane C-L-e (approach) 5.670
Airplane C-M-e (cruise)
Forward C.G. -1.061
Aft C.G. -0.625
Airplane C-M-e (approach)
Forward C.G. -1.116
Aft C.G. -0.673
C-L-1-H (cruise) 0.778
C-L-1-H (approach) 0.803
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<th>Condition</th>
<th>C-l-o</th>
<th>s</th>
<th>i-h</th>
<th>6-e</th>
<th>6-flaps</th>
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Lift Curve Equations:

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<th>i-h</th>
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<td>Min Ctrl-fm</td>
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Take-off Rotation Calculations:

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<td>Drag Moment Arm z-rd</td>
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<td>Lift at T-O</td>
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<td>Take-off Weight W-to</td>
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<tr>
<td>X-mg</td>
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<td>X-cg</td>
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<td>Z-mg</td>
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<td>q-bar T.O.A.</td>
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### 36 Passenger Airplane: Calculations for Cruise and M.C. at Fwd and Aft C.G.

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#### Moments of Inertia:

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#### Wing:

<table>
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<td>Span ft</td>
<td>84.300</td>
</tr>
<tr>
<td>M/C ft</td>
<td>7.450</td>
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<tr>
<td>Aspect Ratio</td>
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<td>Leading Edge Sweep rad</td>
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<td>Semichord Sweep rad</td>
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<td>C-L-o</td>
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<td>C-mo-wing (approach)</td>
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#### Horizontal Tail:

<table>
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<td>Span ft</td>
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<td>Root Chord</td>
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<td>M/C ft</td>
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<tr>
<td>LE Sweep rad</td>
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<tr>
<td>c/2 Sweep rad</td>
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#### Horizontal Tail Lift Curves:

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<td>C-L-s (cruise)</td>
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<td>B_i</td>
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#### Vertical Tail Lift Curves:

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<tr>
<td>K_i</td>
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<td>C-L-s (cruise)</td>
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<tr>
<td>k_i</td>
<td>0.68</td>
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<tr>
<td>C-L-s (app)</td>
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<tr>
<td>B_i</td>
<td>0.71</td>
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<tr>
<td>Parameter</td>
<td>Value</td>
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<tr>
<td>-----------------------------------------------</td>
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<tr>
<td>V.T. LE Sweep rad</td>
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<td>V.T. c/2 Sweep rad</td>
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<td>V.T. Taper Ratio</td>
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<tr>
<td>V.T. Moment Arm 1-v</td>
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<td>Approach Alpha e (rad)</td>
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<td>Approach 1-v</td>
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<td>1*ide/db</td>
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<table>
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<th>Engine Mounting Bar:</th>
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<tbody>
<tr>
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<tr>
<td>Bar Span ft</td>
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<td>Bar NGC ft</td>
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<td>Bar Aspect Ratio</td>
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<tr>
<td>Bar LE Sweep rad</td>
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<td>X-bar ac-h</td>
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<td>1 - downwash</td>
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<td>Bar q-bar corr. (eta-h)</td>
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<table>
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<tbody>
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<td>Z-e</td>
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<tr>
<td>Z-e dot</td>
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<td>W-e</td>
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<td>C-n-t dot</td>
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<tr>
<td>W-n-q dot</td>
<td>-0.633</td>
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</table>
### Short Period:
- **Frequency**: 2.233, 1.621, 1.254, 1.026
- **Damping Ratio**: 0.442, 0.647, 0.641, 0.633
- **N-«**: 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, 0.216, 0.220
- **Omega * Zeta**: 0.294, 0.277, 0.259, 0.251

### Verify Class I Handling Qualities:
- **Short Period**:
  - Below max freq.: yes
  - Above min freq.: yes
  - Damping: yes
- **Dutch Roll**:
  - Frequency: yes
  - Damping Ratio: yes
  - Omega * Zeta: yes

### Engine-Out Calculations:
- **C-y-6-r**: -0.324
- **C-n-6-r**: 0.100
- Required 6-r (rad): 0.399
- Required 6-r (deg): 22.888

### Lift and Pitching Moment Calculations:
- **Airplane C-L-c (cruise)**: 0.454
- **Airplane C-L-c (approach)**: 0.461
- **Airplane C-L-a (cruise)**: 5.579
- **Airplane C-L-a (approach)**: 5.670
- **Airplane C-M-c (cruise)**: Forward C.G.: -1.041
  Aft C.G.: -0.383
- **Airplane C-M-c (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
<table>
<thead>
<tr>
<th>Condition</th>
<th>C-L-4-* (cruise)</th>
<th>C-L-4-* (approach)</th>
<th>C-M-i-h (cruise)</th>
<th>Pitching Moment Eqns: Condition</th>
<th>C-m-o</th>
<th>C-L</th>
<th>1-h</th>
<th>6-m</th>
<th>6-flaps</th>
<th>Thrust:</th>
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<tr>
<td>Forward C.G.</td>
<td>-3.303</td>
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<tr>
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Lift Curve Equations: Condition | C-1-\* | C-M-i-h | 6-m | 6-flaps |
<table>
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Pitching Moment Equations: Condition | C-m-o | C-L-4-e (cruise) | C-M-i-h (cruise) | Forward C.G. | Aft C.G. |
<table>
<thead>
<tr>
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AC-m-o H.T. Forward C.G. | 0.152 |
Aft C.G. | 0.146 |
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<td>Elevator Deflection</td>
<td>14.71 deg</td>
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</table>
### 36 Passenger Airplane: Calculations for Cruise and N.C. at Fwd and Aft C.G.

**Cruise Mach Number**: 0.700

**Section Lift Curve Slope**: 6.000

**Wing-Body ac shift**: -0.090

**x-bar C.G.**: 0.385

**Min Control Dynamic Pres.**: 51.170

**Cruise Dynamic Pressure**: 215.600

**Min Control Speed**: 207.500

**Cruise Speed fps**: 696.290

**1/deg to 1/deg conversion**: 0.017

---

### Moments of Inertia:

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<td>237,382</td>
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### Fuselage:

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<td>Fuselage Width</td>
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<td>Fuselage Length</td>
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### Wing:

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<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing Area sqft</td>
<td>592,000</td>
</tr>
<tr>
<td>Wing Span ft</td>
<td>84,300</td>
</tr>
<tr>
<td>Wing N.GC ft</td>
<td>7,450</td>
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<tr>
<td>Aspect Ratio</td>
<td>12.000</td>
</tr>
<tr>
<td>Leading Edge Sweep rad</td>
<td>0.262</td>
</tr>
<tr>
<td>Semi-chord Sweep rad</td>
<td>0.194</td>
</tr>
<tr>
<td>c-t-o</td>
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<td>c-u-o-wing (cruise)</td>
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<tr>
<td>c-u-o-wing (approach)</td>
<td>-0.045</td>
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### Horizontal Tail:

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<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total H.T. Area sqft</td>
<td>120,000</td>
</tr>
<tr>
<td>H.T. Area (each) sqft</td>
<td>120,000</td>
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<tr>
<td>H.T. Span ft</td>
<td>26.569</td>
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<tr>
<td>H.T. Root Chord</td>
<td>6.022</td>
</tr>
<tr>
<td>H.T. N.GC ft</td>
<td>4.684</td>
</tr>
<tr>
<td>H.T. Aspect Ratio</td>
<td>5.883</td>
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<tr>
<td>H.T. LE Sweep rad</td>
<td>0.438</td>
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<tr>
<td>H.T. c/2 Sweep rad</td>
<td>0.314</td>
</tr>
<tr>
<td>H.T. Taper Ratio</td>
<td>0.500</td>
</tr>
<tr>
<td>x-bar ac-h</td>
<td>4.676</td>
</tr>
<tr>
<td>i - downwash</td>
<td>0.746</td>
</tr>
<tr>
<td>H.T. q-bar corr. (sta-h)</td>
<td>1.000</td>
</tr>
<tr>
<td>Elevator effectiveness ve</td>
<td>0.540</td>
</tr>
</tbody>
</table>

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### Vertical Tail:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Total V.T. Area sqft</td>
<td>170,000</td>
</tr>
<tr>
<td>V.T. Area (each) sqft</td>
<td>170,000</td>
</tr>
<tr>
<td>V.T. Span ft</td>
<td>15.400</td>
</tr>
<tr>
<td>V.T. N.GC ft</td>
<td>12.000</td>
</tr>
<tr>
<td>V.T. Aspect Ratio</td>
<td>1.40</td>
</tr>
<tr>
<td>V.T. Effective Asp. Ratio</td>
<td>1.960</td>
</tr>
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### Vertical Tail Lift Curves:

<p>| | |</p>
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Ki</td>
<td>1.0366</td>
</tr>
<tr>
<td>C-L-e (cruise)</td>
<td>2.0002</td>
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</tbody>
</table>

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### Horizontal Tail Lift Curves:

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<thead>
<tr>
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<tbody>
<tr>
<td>Ki</td>
<td>1.0630</td>
</tr>
<tr>
<td>C-L-e (cruise)</td>
<td>3.8395</td>
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</tbody>
</table>

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### Wing Lift Curves:

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<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Ki</td>
<td>1.0544</td>
</tr>
<tr>
<td>C-L-e (cruise)</td>
<td>4.7089</td>
</tr>
</tbody>
</table>

---

**Note:** All Results in RADIANWS

---

**Cruise Speed - W-to C.G.**: 0.280

**Aft - W-to C.G.**: 0.385
### Engine Mounting Bar:
- Bar Area sq ft: 112.000
- Bar Span ft: 10.200
- Bar Aspect Ratio: 1.080
- Bar LE Sweep rad: 0.436
- Bar c/2 Sweep rad: 0.281
- Bar Taper Ratio: 0.860
- Engine Bar Lift Curves:
  - $k$: 0.71
  - $C_{L_{\text{bar}}}$ (cruise): 1.5395
  - $C_{L_{\text{bar}}}$ (app): 1.5317
- Approach Alpha $\alpha$ (rad): 0.828
- Approach $\alpha$ (rad): 1.000
- Engine Bar corr. (eta-h): 1.000

### Total Derivatives:
- 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:

<table>
<thead>
<tr>
<th>non-dim. Derivatives</th>
<th>Cruise-fwd</th>
<th>Cruise-aft</th>
<th>Min Ctrl-fwd</th>
<th>Min Ctrl-aft</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{L_{\text{e}}}$ Airplane</td>
<td>5.579</td>
<td>5.579</td>
<td>5.670</td>
<td>5.670</td>
</tr>
<tr>
<td>$C_{m_{\text{e}}}$ Airplane</td>
<td>-0.969</td>
<td>-0.383</td>
<td>-1.024</td>
<td>-0.429</td>
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<tr>
<td>$C_{L_{\text{e}}}$-dot</td>
<td>1.738</td>
<td>1.696</td>
<td>1.793</td>
<td>1.750</td>
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<tr>
<td>$C_{m_{\text{e}}}$-dot</td>
<td>-7.640</td>
<td>-7.280</td>
<td>-7.882</td>
<td>-7.510</td>
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<tr>
<td>$C_{\alpha}$</td>
<td>-33.279</td>
<td>-31.651</td>
<td>-34.326</td>
<td>-32.650</td>
</tr>
<tr>
<td>$C_{\gamma}$</td>
<td>-1.168</td>
<td>-1.168</td>
<td>-1.232</td>
<td>-1.232</td>
</tr>
<tr>
<td>$C_{\alpha}$-dot</td>
<td>0.118</td>
<td>0.118</td>
<td>0.153</td>
<td>0.153</td>
</tr>
<tr>
<td>$C_{\gamma}$-dot</td>
<td>0.513</td>
<td>0.513</td>
<td>0.562</td>
<td>0.582</td>
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<tr>
<td>$C_{\alpha}$-r</td>
<td>-0.149</td>
<td>-0.149</td>
<td>-0.179</td>
<td>-0.179</td>
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### Dimensional Derivatives:

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<tr>
<th>dimensional Derivatives</th>
<th>Cruise-fwd</th>
<th>Cruise-aft</th>
<th>Min Ctrl-fwd</th>
<th>Min Ctrl-aft</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{\alpha}$</td>
<td>-371.162</td>
<td>-998.019</td>
<td>-153.672</td>
<td>-240.704</td>
</tr>
<tr>
<td>$I_{\alpha}$-dot</td>
<td>-1.062</td>
<td>-1.624</td>
<td>-0.872</td>
<td>-1.324</td>
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<tr>
<td>$M_{\alpha}$</td>
<td>-3.881</td>
<td>-1.751</td>
<td>-0.974</td>
<td>-0.666</td>
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<tr>
<td>$M_{\alpha}$-dot</td>
<td>-0.164</td>
<td>-0.178</td>
<td>-0.135</td>
<td>-0.146</td>
</tr>
<tr>
<td>$M_{\alpha}$-p</td>
<td>-0.713</td>
<td>-0.774</td>
<td>-0.586</td>
<td>-0.636</td>
</tr>
<tr>
<td>Y-Th:</td>
<td>-133.391</td>
<td>-208.922</td>
<td>-33.396</td>
<td>-52.305</td>
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<tr>
<td>-------</td>
<td>----------</td>
<td>----------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Y-th:</td>
<td>3.546</td>
<td>5.355</td>
<td>3.207</td>
<td>5.023</td>
</tr>
<tr>
<td>N-th:</td>
<td>3.757</td>
<td>4.980</td>
<td>1.153</td>
<td>1.528</td>
</tr>
<tr>
<td>N-th:</td>
<td>-0.286</td>
<td>-0.379</td>
<td>-0.274</td>
<td>-0.363</td>
</tr>
</tbody>
</table>

**Short Period:**

| Frequency | 2.129 | 1.691 | 1.186 | 1.097 |
| Damping Ratio | 0.421 | 0.705 | 0.616 | 0.685 |
| N-th | 19.806 | 31.023 | 4.701 | 7.363 |

**Dutch Roll:**

| Frequency | 1.946 | 2.248 | 1.086 | 1.258 |
| Damping Ratio | 0.123 | 0.151 | 0.200 | 0.245 |
| Omega * Zeta | 0.239 | 0.340 | 0.217 | 0.306 |

**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-d-r | -0.324 |
| C-n-d-r | 0.100  |
| Required d-r (rad) | 0.399 |
| Required d-r (deg) | 22.888 |

**Lift and Pitching Moment Calculations:**

<p>| 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-c (cruise) | Forward C.G. | -0.969 |
| | Aft C.G. | -0.383 |
| Airplane C-M-c (approach) | Forward C.G. | -1.024 |
| | Aft C.G. | -0.429 |
| C-L-t-H (cruise) | 0.778 |
| C-L-t-H (approach) | 0.803 |</p>
<table>
<thead>
<tr>
<th>Condition</th>
<th>C-l-o</th>
<th>e</th>
<th>i-h</th>
<th>d-e</th>
<th>d-flaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cruise</td>
<td>0.170</td>
<td>0.097</td>
<td>0.014</td>
<td>0.007</td>
<td>0.027</td>
</tr>
<tr>
<td>Approach</td>
<td>0.170</td>
<td>0.099</td>
<td>0.014</td>
<td>0.008</td>
<td>0.027</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Condition</th>
<th>C-m-o</th>
<th>C-l</th>
<th>i-h</th>
<th>d-e</th>
<th>C-m-b-f</th>
<th>Thrust</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cruise-fwd</td>
<td>-0.006</td>
<td>-0.174</td>
<td>-0.057</td>
<td>-0.031</td>
<td>-0.004</td>
<td></td>
</tr>
<tr>
<td>Cruise-aft</td>
<td>-0.006</td>
<td>-0.063</td>
<td>-0.057</td>
<td>-0.031</td>
<td>-0.004</td>
<td></td>
</tr>
<tr>
<td>Approach-fwd</td>
<td>0.005</td>
<td>-0.181</td>
<td>-0.059</td>
<td>-0.032</td>
<td>-0.390</td>
<td>-0.132</td>
</tr>
<tr>
<td>Approach-aft</td>
<td>0.005</td>
<td>-0.076</td>
<td>-0.059</td>
<td>-0.032</td>
<td>-0.390</td>
<td>-0.132</td>
</tr>
</tbody>
</table>

| C-m-o H.T. | Forward C.G. | 0.151 |
|           | Aft C.G.     | 0.148 |
**Take-off Rotation Calculations:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Take-off Thrust T</td>
<td>15,461.40</td>
</tr>
<tr>
<td>Thrust Moment Arm z-t</td>
<td>1.92</td>
</tr>
<tr>
<td>Drag at T-O D</td>
<td>2,000.00</td>
</tr>
<tr>
<td>Drag Moment Arm z-d</td>
<td>2.00</td>
</tr>
<tr>
<td>Lift at T-O</td>
<td>5,000.00</td>
</tr>
<tr>
<td>Take-off Weight</td>
<td>25,954.00</td>
</tr>
<tr>
<td>X-mg</td>
<td>5.00</td>
</tr>
<tr>
<td>X-cg</td>
<td>2.02</td>
</tr>
<tr>
<td>Z-mg</td>
<td>7.70</td>
</tr>
<tr>
<td>X-ac-wb</td>
<td>1.19</td>
</tr>
<tr>
<td>X-ac-h</td>
<td>34.84</td>
</tr>
<tr>
<td>Wheel-ground friction</td>
<td>0.02</td>
</tr>
<tr>
<td>q-bar T.G.R.</td>
<td>50.00</td>
</tr>
<tr>
<td>C-l-o-h</td>
<td>0.17</td>
</tr>
<tr>
<td>C-w-ac-wb</td>
<td>-0.09</td>
</tr>
<tr>
<td>H.T. incidence for rotat.</td>
<td>0.16 rad</td>
</tr>
<tr>
<td>Elevator Deflection</td>
<td>16.84 deg</td>
</tr>
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*Original page is of poor quality*
### 50 Passenger Airplane Calculations for Cruise and M.C. at Fwd and Aft C.G.

<table>
<thead>
<tr>
<th>Property</th>
<th>Fwd</th>
<th>Aft</th>
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<tbody>
<tr>
<td>Cruise Mach Number</td>
<td>0.700</td>
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<tr>
<td>Section Lift Curve Slope</td>
<td>6.000</td>
<td>Forward C.G. 0.530</td>
</tr>
<tr>
<td>Wing-Body ac shift</td>
<td>-0.090</td>
<td>Aft C.G. 0.603</td>
</tr>
<tr>
<td>I-bar C.G.</td>
<td>0.603</td>
<td></td>
</tr>
<tr>
<td>Min Ctrl Dyna Pres.</td>
<td>51.170</td>
<td>approach a.c. 0.673</td>
</tr>
<tr>
<td>Cruise Dynamic Pressure</td>
<td>215.600</td>
<td>cruise a.c. 0.664</td>
</tr>
<tr>
<td>Min Ctrl Speed fps</td>
<td>207.500</td>
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<tr>
<td>Cruise Speed fps</td>
<td>696.290</td>
<td>static margin -0.061 -0.134</td>
</tr>
<tr>
<td>1/rad to 1/deg conversion</td>
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<td></td>
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<tr>
<td>Moments of Inertia:</td>
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<tr>
<td>I=xx</td>
<td>141,865</td>
<td>72,363</td>
</tr>
<tr>
<td>I=yy</td>
<td>465,510</td>
<td>406,670</td>
</tr>
<tr>
<td>I=zz</td>
<td>560,046</td>
<td>457,113</td>
</tr>
<tr>
<td>Heights</td>
<td>43,141</td>
<td>25,976</td>
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<tr>
<td>Fuselage</td>
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<td>Fuselage Height</td>
<td>6.050</td>
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<tr>
<td>Fuselage Width</td>
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<tr>
<td>Fuselage Length</td>
<td>96.330</td>
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<tr>
<td>C-n-«-body</td>
<td>-0.141</td>
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<td>Wing:</td>
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<td>Wing Area sqft</td>
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<tr>
<td>Wing Span ft</td>
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<tr>
<td>Wing MEC ft</td>
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</tr>
<tr>
<td>Aspect Ratio</td>
<td>12.000</td>
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</tr>
<tr>
<td>Leading Edge Sweep rad</td>
<td>0.262</td>
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<tr>
<td>Semi-chord Sweep rad</td>
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<tr>
<td>C-L-o</td>
<td>0.170</td>
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<td>C-m-o-wing</td>
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<td>C-m-o-wing (approach)</td>
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<tr>
<td>Horizontal Tail:</td>
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<tr>
<td>Total H.T. Area sqft</td>
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<tr>
<td>H.T. Area (each) sqft</td>
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<td>26.569</td>
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<tr>
<td>H.T. Root Chord</td>
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<tr>
<td>H.T. MEC ft</td>
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<td>H.T. Aspect Ratio</td>
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<td>H.T. LE Sweep rad</td>
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<td>H.T. c/2 Sweep rad</td>
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<td>H.T. Taper Ratio</td>
<td>0.300</td>
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</tr>
<tr>
<td>X-bar ac-h</td>
<td>6.040</td>
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<tr>
<td>1 - docwash</td>
<td>0.746</td>
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<tr>
<td>H.T. q-bar corr. (eta-h)</td>
<td>1.000</td>
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</tr>
<tr>
<td>Elevator effectiveness w</td>
<td>0.540</td>
<td></td>
</tr>
<tr>
<td>Vertical Tail:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total V.T. Area sqft</td>
<td>170.000</td>
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</tr>
<tr>
<td>V.T. Area (each) sqft</td>
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</tr>
<tr>
<td>V.T. Span ft</td>
<td>15.400</td>
<td></td>
</tr>
<tr>
<td>V.T. MEC ft</td>
<td>12.000</td>
<td></td>
</tr>
<tr>
<td>V.T. Aspect Ratio</td>
<td>1.400</td>
<td></td>
</tr>
<tr>
<td>V.T. Effective Asp. Ratio</td>
<td>1.960</td>
<td></td>
</tr>
</tbody>
</table>

### Wing Lift Curves:

<table>
<thead>
<tr>
<th>K</th>
<th>C-L-w (cruise)</th>
<th>C-L-w (app)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0544</td>
<td>4.7089</td>
<td>4.7794</td>
</tr>
<tr>
<td>0.6200</td>
<td>3.8395</td>
<td>3.9610</td>
</tr>
<tr>
<td>0.7141</td>
<td>2.0802</td>
<td>2.2314</td>
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</tbody>
</table>

### Horizontal Tail Lift Curves:

<table>
<thead>
<tr>
<th>K</th>
<th>C-L-w (cruise)</th>
<th>C-L-w (app)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0629</td>
<td>3.8395</td>
<td>3.9610</td>
</tr>
<tr>
<td>0.6200</td>
<td>2.0802</td>
<td>2.2314</td>
</tr>
<tr>
<td>0.7141</td>
<td>1.9600</td>
<td>2.1114</td>
</tr>
</tbody>
</table>

### Vertical Tail Lift Curves:

<table>
<thead>
<tr>
<th>K</th>
<th>C-L-w (cruise)</th>
<th>C-L-w (app)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0365</td>
<td>2.0802</td>
<td>2.2314</td>
</tr>
<tr>
<td>0.68</td>
<td>1.9600</td>
<td>2.1114</td>
</tr>
<tr>
<td>0.71</td>
<td>1.9600</td>
<td>2.1114</td>
</tr>
<tr>
<td>Parameter</td>
<td>Value</td>
<td></td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-----------</td>
<td></td>
</tr>
<tr>
<td>V.T. LE Sweep rad</td>
<td>0.785</td>
<td></td>
</tr>
<tr>
<td>V.T. c/2 Sweep rad</td>
<td>0.687</td>
<td></td>
</tr>
<tr>
<td>V.T. Taper Ratio</td>
<td>0.330</td>
<td></td>
</tr>
<tr>
<td>V.T. Moment Arm 1-v</td>
<td>32.342</td>
<td></td>
</tr>
<tr>
<td>Approach Alpha e (rad)</td>
<td>0.1745</td>
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</tr>
<tr>
<td>Approach 1-v</td>
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</tr>
<tr>
<td>1+tdv</td>
<td>1.477</td>
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</tr>
<tr>
<td>Engine Mounting Bar:</td>
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<td></td>
</tr>
<tr>
<td>Bar Area sqft</td>
<td>112.000</td>
<td></td>
</tr>
<tr>
<td>Bar Span ft</td>
<td>11.000</td>
<td></td>
</tr>
<tr>
<td>Bar MEC ft</td>
<td>10.200</td>
<td></td>
</tr>
<tr>
<td>Bar Aspect Ratio</td>
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<td></td>
</tr>
<tr>
<td>Bar LE Sweep rad</td>
<td>0.436</td>
<td></td>
</tr>
<tr>
<td>Bar c/2 Sweep rad</td>
<td>0.281</td>
<td></td>
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<tr>
<td>Bar Taper Ratio</td>
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<tr>
<td>X-bar ac-h</td>
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<tr>
<td>1 - downwash</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Bar q-bar corr. (eta-h)</td>
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<tr>
<td>Total Take-off Thrust lbs</td>
<td>18,929</td>
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<tr>
<td>Total Cruise Thrust (lbs)</td>
<td>4,047</td>
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<tr>
<td>Z-T (vertical mom. arm)</td>
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</tr>
<tr>
<td>Y-T (horizontal mom. arm)</td>
<td>10.000</td>
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<tr>
<td>Cruise-fwd Cruise-aft Min Ctrl-fwd Min Ctrl-aft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-l-e Airplane</td>
<td>5.579</td>
<td>5.579</td>
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<tr>
<td>C-n-e Airplane</td>
<td>-0.749</td>
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<tr>
<td>C-l-e dot</td>
<td>2.178</td>
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<td>C-n-e dot</td>
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<td>C-n-q</td>
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<td>C-y-d</td>
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<td>C-n-o</td>
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<td>C-y-r</td>
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<tr>
<td>C-n-r</td>
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<td>-0.260</td>
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<table>
<thead>
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<tr>
<td>Cruise-fwd Cruise-aft Min Ctrl-fwd Min Ctrl-aft</td>
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<td>Z-e dot</td>
<td>1.109</td>
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<tr>
<td>N-e</td>
<td>-1.529</td>
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<tr>
<td>N-e dot</td>
<td>-0.131</td>
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<td>N-q</td>
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</table>
Y-r: 3.900 6.477 3.468 5.759  
M-fl: 3.663 4.649 1.043 1.323  
M-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-s 16.507 27.412 3.918 6.506  

Dutch Roll:  
Frequency 1.521 2.165 1.030 1.167  
Damping Ratio 0.117 0.146 0.196 0.242  
Omega * Zeta 0.225 0.318 0.202 0.263  

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-4-r -0.324  
C-m-4-r 0.129  
Required 4-r (rad) 0.359  
Required 4-r (deg) 20.542  

Lift and Pitching Moment Calculations:  
Airplane X-ac (cruise) 0.664  
Airplane X-ac (approach) 0.673  
Airplane C-I-s (cruise) 5.579  
Airplane C-I-s (approach) 5.670  
Airplane C-M-s (cruise)  
    Forward C.G. -0.749  
    Aft C.G. -0.341  
Airplane C-M-s (approach)  
    Forward C.G. -0.806  
    Aft C.G. -0.395  
C-I-I-H (cruise) 0.778  
C-I-I-H (approach) 0.803  

<table>
<thead>
<tr>
<th>Condition</th>
<th>Lift Curve Equations</th>
<th>Pitching Moment Eqns</th>
<th>Thrust</th>
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<td></td>
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<tr>
<td></td>
<td>Condition</td>
<td>C-L</td>
<td>C-M-h</td>
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<tr>
<td>Cruise</td>
<td></td>
<td>0.170</td>
<td>0.197</td>
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<td>Approach</td>
<td></td>
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<td>0.099</td>
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<tr>
<td>Pitching Moment Eqns:</td>
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</tr>
<tr>
<td></td>
<td>Condition</td>
<td>C-m-o</td>
<td>C-L</td>
</tr>
<tr>
<td>Cruise-fwd</td>
<td></td>
<td>0.017</td>
<td>-0.134</td>
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<tr>
<td>Cruise-aft</td>
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<tr>
<td>Approach-fwd</td>
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<td>Approach-aft</td>
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<td>Forward C.G.</td>
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<tr>
<td></td>
<td>Aft C.G.</td>
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Take-off Rotation Calculations:

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<th>Value</th>
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<td>Take-off Thrust T</td>
<td>18,928.80</td>
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<tr>
<td>Thrust Moment Arm z-t</td>
<td>1.92</td>
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<tr>
<td>Drag at T-O D</td>
<td>2,000.00</td>
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<tr>
<td>Drag Moment Arm z-d</td>
<td>2.00</td>
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<tr>
<td>Lift at T-O</td>
<td>5,000.00</td>
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<tr>
<td>Take-off Weight</td>
<td>43,141.00</td>
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<tr>
<td>X-mg</td>
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<tr>
<td>X-cg</td>
<td>3.92</td>
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<tr>
<td>Z-mg</td>
<td>7.67</td>
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<td>X-ac-wb</td>
<td>1.19</td>
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<tr>
<td>X-ac-h</td>
<td>45.00</td>
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<tr>
<td>Wheel-ground friction ( \mu )</td>
<td>0.02</td>
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<tr>
<td>q-bar T.O.R.</td>
<td>50.00</td>
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<tr>
<td>C-l-o-h</td>
<td>0.17</td>
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<tr>
<td>C-w-ac-wb</td>
<td>-0.10</td>
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<tr>
<td>H.T. incidence for rotat.</td>
<td>0.06 rad</td>
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<tr>
<td>Elevator Deflection</td>
<td>3.32 deg</td>
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<td></td>
<td>6.15 deg</td>
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### 75 Passenger Twin-body:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<td>Cruise Mach Number</td>
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<tr>
<td>Section Lift Curve Slope</td>
<td>6.000</td>
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</tr>
<tr>
<td>Wing-Body ac shift</td>
<td>-0.140</td>
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</tr>
<tr>
<td>I-bar c.g.</td>
<td>0.769</td>
<td></td>
</tr>
<tr>
<td>Min. Dntrl Dynamic Pres.</td>
<td>51.170</td>
<td></td>
</tr>
<tr>
<td>Cruise Dynamic Pressure</td>
<td>215.600</td>
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</tr>
<tr>
<td>Min. Dntrl Speed fps</td>
<td>207.500</td>
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</tr>
<tr>
<td>Cruise Speed fps</td>
<td>696.290</td>
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</tr>
<tr>
<td>1/deg to 1/deg conversion</td>
<td>0.017</td>
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### Note: All Results in RADIANS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Forward C.G.</th>
<th>Aft C.G.</th>
<th>Cruise A.C.</th>
<th>Approach A.C.</th>
<th>Static Margin</th>
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<tbody>
<tr>
<td>Section Lift Curve Slope</td>
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<td>6.02</td>
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<td>-0.140</td>
<td>-0.140</td>
<td>-0.140</td>
<td>-0.140</td>
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<tr>
<td>I-bar c.g.</td>
<td>0.769</td>
<td>0.769</td>
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<td>0.769</td>
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<tr>
<td>Min. Dntrl Dynamic Pres.</td>
<td>51.170</td>
<td>51.170</td>
<td>51.170</td>
<td>51.170</td>
<td>51.170</td>
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<tr>
<td>Cruise Dynamic Pressure</td>
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<td>215.600</td>
<td>215.600</td>
<td>215.600</td>
<td>215.600</td>
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<td>Min. Dntrl Speed fps</td>
<td>207.500</td>
<td>207.500</td>
<td>207.500</td>
<td>207.500</td>
<td>207.500</td>
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<tr>
<td>Cruise Speed fps</td>
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<td>696.290</td>
<td>696.290</td>
<td>696.290</td>
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<td>1/deg to 1/deg conversion</td>
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<td>0.017</td>
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### Moments of Inertia:

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<th>Forward</th>
<th>Aft</th>
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<tr>
<td>I-xx</td>
<td>1,355,496</td>
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<tr>
<td>I-yy</td>
<td>565,828</td>
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<td>I-zz</td>
<td>1,772,110</td>
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<td>Weights</td>
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<table>
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<tr>
<th>Fuselage:</th>
<th>8.050</th>
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<tbody>
<tr>
<td>Fuselage Height</td>
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<td>16.100</td>
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<td>C-n-d-body</td>
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<table>
<thead>
<tr>
<th>Wing:</th>
<th>Wing Lift Curves:</th>
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<tbody>
<tr>
<td>Wing Area sqft</td>
<td>1,182,000</td>
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<tr>
<td>Wing Span ft</td>
<td>132.500</td>
</tr>
<tr>
<td>Wing MSC ft</td>
<td>8.970</td>
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<tr>
<td>Aspect Ratio</td>
<td>14.853</td>
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<tr>
<td>Leading Edge Sweep rad</td>
<td>0.201</td>
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<tr>
<td>Semi chord Sweep rad</td>
<td>0.169</td>
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<tr>
<td>C-L-o</td>
<td>0.170</td>
</tr>
<tr>
<td>C-w-o-wing (cruise)</td>
<td>-0.059</td>
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<tr>
<td>C-w-o-wing (approach)</td>
<td>-0.049</td>
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</table>

<table>
<thead>
<tr>
<th>Horizontal Tail:</th>
<th>Horizontal Tail Lift Curves:</th>
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<tbody>
<tr>
<td>Total H.T. Area sqft</td>
<td>410,000</td>
</tr>
<tr>
<td>H.T. Area (each) sqft</td>
<td>410,000</td>
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<tr>
<td>H.T. Span ft</td>
<td>74.770</td>
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<tr>
<td>H.T. Msc ft</td>
<td>5.629</td>
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<tr>
<td>H.T. Aspect Ratio</td>
<td>13.600</td>
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<tr>
<td>H.T. LE Sweep rad</td>
<td>0.070</td>
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<tr>
<td>H.T. c/2 Sweep rad</td>
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<tr>
<td>H.T. Taper Ratio</td>
<td>0.500</td>
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<tr>
<td>X-bar ac-h</td>
<td>4.283</td>
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<td>1 — downwash</td>
<td>0.786</td>
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<td>H.T. q-bar corr. (eta-h)</td>
<td>1.000</td>
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<tr>
<td>Elevator effectiveness re</td>
<td>0.540</td>
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<table>
<thead>
<tr>
<th>Vertical Tail:</th>
<th>Vertical Tail Lift Curves:</th>
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</thead>
<tbody>
<tr>
<td>Total V.T. Area sqft</td>
<td>340,000</td>
</tr>
<tr>
<td>V.T. Area (each) sqft</td>
<td>170,000</td>
</tr>
<tr>
<td>V.T. Span ft</td>
<td>15.400</td>
</tr>
<tr>
<td>V.T. Msc ft</td>
<td>18.000</td>
</tr>
<tr>
<td>V.T. Aspect Ratio</td>
<td>1.44</td>
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<tr>
<td>V.T. Effective Aspect Ratio</td>
<td>1.960</td>
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<tr>
<td>V.T. LE Sweep rad</td>
<td>0.785</td>
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<tr>
<td>V.T. c/2 Sweep (rad)</td>
<td>0.667</td>
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<tr>
<td>-----------------------</td>
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<tr>
<td>V.T. Taper Ratio</td>
<td>0.330</td>
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<tr>
<td>V.T. Moment Arm l-v</td>
<td>23.185</td>
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<td>Approach Alpha ε (rad)</td>
<td>0.1745</td>
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<tr>
<td>Approach l-v</td>
<td>24.64</td>
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<tr>
<td>i+(de/dB)</td>
<td>1.477</td>
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**Engine Mounting Bar:**

<table>
<thead>
<tr>
<th>Bar Area sqft</th>
<th>165.800</th>
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<tbody>
<tr>
<td>Bar Span ft</td>
<td>15.700</td>
</tr>
<tr>
<td>Bar HSC ft</td>
<td>10.620</td>
</tr>
<tr>
<td>Bar Aspect Ratio</td>
<td>1.477</td>
</tr>
<tr>
<td>Bar LE Sweep rad</td>
<td>0.435</td>
</tr>
<tr>
<td>Bar c/2 Sweep rad</td>
<td>0.314</td>
</tr>
<tr>
<td>Bar Taper Ratio</td>
<td>0.614</td>
</tr>
<tr>
<td>X-bar ac-h</td>
<td>0.594</td>
</tr>
<tr>
<td>1 - domwash</td>
<td>1.000</td>
</tr>
<tr>
<td>Bar q-bar corr. (eta-h)</td>
<td>1.000</td>
</tr>
</tbody>
</table>

**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:**

<table>
<thead>
<tr>
<th>Non-dim. Derivatives</th>
<th>Cruise-fwd</th>
<th>Cruise-aft</th>
<th>Min Ctrl-fwd</th>
<th>Min Ctrl-aft</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-L-e Airplane</td>
<td>6.534</td>
<td>6.534</td>
<td>6.596</td>
<td>6.596</td>
</tr>
<tr>
<td>C-m-e Airplane</td>
<td>-1.430</td>
<td>-0.329</td>
<td>-1.294</td>
<td>-0.292</td>
</tr>
<tr>
<td>C-L-e-dot</td>
<td>2.704</td>
<td>2.581</td>
<td>2.707</td>
<td>2.584</td>
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<tr>
<td>C-m-q</td>
<td>-51.250</td>
<td>-46.651</td>
<td>-51.306</td>
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<tr>
<td>C-y-θ</td>
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<td>-1.027</td>
<td>-1.091</td>
<td>-1.091</td>
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<tr>
<td>C-n-θ</td>
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<td>0.034</td>
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<tr>
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<td>0.309</td>
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<tr>
<td>C-n-n</td>
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<td>-0.066</td>
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**Dimensional Derivatives:**

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<tr>
<th>Dimensional Derivatives</th>
<th>Cruise-fwd</th>
<th>Cruise-aft</th>
<th>Min Ctrl-fwd</th>
<th>Min Ctrl-aft</th>
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</thead>
<tbody>
<tr>
<td>Z-e</td>
<td>-750.072</td>
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<td>-286.461</td>
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<tr>
<td>Z-e-dot</td>
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<td>-1.594</td>
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<td>N-e</td>
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<td>N-e-dot</td>
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<td>-0.303</td>
<td>-0.231</td>
<td>-0.241</td>
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<tr>
<td>N-q</td>
<td>-1.492</td>
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<td>-1.169</td>
<td>-1.241</td>
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**Engine Bar Lift Curves:**

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<tr>
<th>K:1.0278</th>
<th>C-L-e (cruise)</th>
<th>1.9622</th>
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<tbody>
<tr>
<td>K:0.58</td>
<td>C-L-e (app)</td>
<td>1.9824</td>
</tr>
<tr>
<td>B:0.71</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Y-θ:
-178.871  -187.890  -29.726  -47.385

### Y-τ:
3.378     5.395     3.067     4.685

### N-θ:
0.639     1.010     0.249     0.394

### N-τ:
-0.098    -0.155    -0.094    -0.149

#### Short Period:
- **Frequency:**
  - 2.840
  - 2.194
  - 1.589
  - 1.440
- **Damping Ratio:**
  - 0.503
  - 0.850
  - 0.719
  - 0.994
- **N-ω:**
  - 23.316
  - 37.166
  - 5.534
  - 6.621

#### Dutch Roll:
- **Frequency:**
  - 0.807
  - 1.022
  - 0.509
  - 0.647
- **Damping Ratio:**
  - 0.165
  - 0.206
  - 0.233
  - 0.292
- **Ω * ζeta:**
  - 0.134
  - 0.212
  - 0.119
  - 0.199

#### Verify Class 1 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
- Ω * ζeta: no, yes, no, yes

#### Engine-Out Calculations:
- C-y-σ-r: -0.324
- C-n-σ-r: 0.060
- Required σ-r (rad): 0.490
- Required σ-r (deg): 28.084

#### Lift and Pitching Moment Calculations:
- Airplane X-ac (cruise): 0.621
- Airplane X-ac (approach): 0.813
- Airplane C-L-e (cruise): 6.534
- Airplane C-L-e (approach): 6.596
- Airplane C-M-e (cruise):
  - Forward C.G.: -1.430
  - Aft C.G.: -0.339
- Airplane C-M-e (approach):
  - Forward C.G.: -1.394
  - Aft C.G.: -0.292
- C-L-i-H (cruise): 1.614
- C-L-i-H (approach): 1.718
- C-L-ñ-e (cruise): 0.927
### Lift Curve Equations

<table>
<thead>
<tr>
<th>Condition</th>
<th>( C-l-o )</th>
<th>( s )</th>
<th>( i-h )</th>
<th>( 6-e )</th>
<th>( 6-flaps )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cruise</td>
<td>0.170</td>
<td>0.114</td>
<td>0.030</td>
<td>0.016</td>
<td>0.027</td>
</tr>
<tr>
<td>Approach</td>
<td>0.170</td>
<td>0.115</td>
<td>0.030</td>
<td>0.016</td>
<td>0.027</td>
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</table>

### Pitching Moment Equations

<table>
<thead>
<tr>
<th>Condition</th>
<th>( C-m-o )</th>
<th>C-L</th>
<th>( i-h )</th>
<th>( 6-e )</th>
<th>( 6-flaps )</th>
<th>Thrust</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cruise-fwd</td>
<td>0.081</td>
<td>-0.219</td>
<td>-0.104</td>
<td>-0.056</td>
<td>-0.008</td>
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</tr>
<tr>
<td>Cruise-aft</td>
<td>0.081</td>
<td>-0.052</td>
<td>-0.104</td>
<td>-0.056</td>
<td>-0.008</td>
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<tr>
<td>Approach-fwd</td>
<td>0.090</td>
<td>-0.211</td>
<td>-0.104</td>
<td>-0.056</td>
<td>-0.390</td>
<td>-0.361</td>
</tr>
<tr>
<td>Approach-aft</td>
<td>0.090</td>
<td>-0.044</td>
<td>-0.104</td>
<td>-0.056</td>
<td>-0.390</td>
<td>-0.361</td>
</tr>
</tbody>
</table>

<p>| 4C-m-o H.T. Forward C.G. | 0.064 |
| Aft C.G.                 | 0.061 |</p>
<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Take-off Thrust T</td>
<td>37,890.60</td>
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<tr>
<td>Thrust Moment Arm z-t</td>
<td>5.17</td>
</tr>
<tr>
<td>Drag at T-O D</td>
<td>3,500.00</td>
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<tr>
<td>Drag Moment Arm z-d</td>
<td>2.00</td>
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<tr>
<td>Lift at T-O</td>
<td>10,000.00</td>
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<tr>
<td>Take-off Weight W-to</td>
<td>71,419.00</td>
</tr>
<tr>
<td>X-mg</td>
<td>5.00</td>
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<tr>
<td>X-cy</td>
<td>5.40</td>
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<tr>
<td>X-mg</td>
<td>7.70</td>
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<tr>
<td>X-ac-wb</td>
<td>0.99</td>
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<tr>
<td>X-ac-h</td>
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<td>Wheel-ground friction</td>
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<td>q-bar T.O.R.</td>
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<td>C-I-o-h</td>
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<td>C-s-ac-wb</td>
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<tr>
<td>H.T. incidence for rotat.</td>
<td>0.02 rad</td>
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<tr>
<td>Elevator Deflection</td>
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### 100 Passenger Twin-body:

<table>
<thead>
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<th>Parameter</th>
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<tr>
<td>Cruise Mach Number</td>
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<tr>
<td>Section Lift Curve Slope</td>
<td>6.000</td>
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<tr>
<td>Wing-Body ac shift</td>
<td>-0.140</td>
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<tr>
<td>X-bar C.G.</td>
<td>0.802</td>
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<tr>
<td>Min Ctrln Dynamic Pres.</td>
<td>50.286</td>
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<td>Cruise Dynamic Pressure</td>
<td>215.600</td>
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<td>Min Ctrln Speed fps</td>
<td>207.500</td>
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<tr>
<td>Cruise Speed fps</td>
<td>696.290</td>
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<td>I/rad to 1/deg conversion</td>
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#### Moments of Inertia:

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<tbody>
<tr>
<td>I-xx</td>
<td>1,646,675</td>
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<tr>
<td>I-yy</td>
<td>765,820</td>
</tr>
<tr>
<td>I-zz</td>
<td>2,326,135</td>
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<tr>
<td>Weights</td>
<td>85,044</td>
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#### Fuselage:

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<tr>
<td>Fuselage Height</td>
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<tr>
<td>Fuselage Width</td>
<td>16.100</td>
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<tr>
<td>Fuselage Length</td>
<td>95.330</td>
</tr>
<tr>
<td>C-n-B-body</td>
<td>-0.129</td>
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</table>

#### Wing:

<table>
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<tr>
<th>Parameter</th>
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<tbody>
<tr>
<td>Wing Area sqft</td>
<td>1,182,000</td>
</tr>
<tr>
<td>Wing Span ft</td>
<td>132.500</td>
</tr>
<tr>
<td>Wing MEC ft</td>
<td>8.570</td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td>14.843</td>
</tr>
<tr>
<td>Leading Edge Sweep rad</td>
<td>0.201</td>
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<tr>
<td>Semichord Sweep rad</td>
<td>0.169</td>
</tr>
<tr>
<td>C-L-o</td>
<td>0.170</td>
</tr>
<tr>
<td>C-e-o-wing (cruise)</td>
<td>-0.059</td>
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<tr>
<td>C-e-o-wing (approach)</td>
<td>-0.049</td>
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</tbody>
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#### Horizontal Tail:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Total H.T. Area sqft</td>
<td>410.000</td>
</tr>
<tr>
<td>H.T. Area (each) sqft</td>
<td>410.000</td>
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<tr>
<td>H.T. Span ft</td>
<td>74.770</td>
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<tr>
<td>H.T. MEC ft</td>
<td>5.629</td>
</tr>
<tr>
<td>H.T. Aspect Ratio</td>
<td>13.800</td>
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<tr>
<td>H.T. LE Sweep rad</td>
<td>0.070</td>
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<tr>
<td>H.T. c/E Sweep rad</td>
<td>0.032</td>
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<tr>
<td>H.T. Taper Ratio</td>
<td>0.500</td>
</tr>
<tr>
<td>X-bar ac-h</td>
<td>4.942</td>
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<tr>
<td>1 - downwash</td>
<td>0.276</td>
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<tr>
<td>H.T. q-bar corr. (eta-h)</td>
<td>1.000</td>
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<tr>
<td>Elevator effectiveness Ù</td>
<td>0.540</td>
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#### Vertical Tail:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Total V.T. Area sqft</td>
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<tr>
<td>V.T. Area (each) sqft</td>
<td>170.000</td>
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<tr>
<td>V.T. Span ft</td>
<td>15.400</td>
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<tr>
<td>V.T. MEC ft</td>
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<tr>
<td>V.T. Aspect Ratio</td>
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<tr>
<td>V.T. Effective Resp. Ratio</td>
<td>1.960</td>
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<tr>
<td>V.T. LE Sweep rad</td>
<td>0.785</td>
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#### Note: All Results in RADIANS

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

### Wing Lift Curves:

- K:1.0493 C-L-i (cruise) 4.9096
- k:0.6820 C-L-i (app) 4.9663

### Horizontal Tail Lift Curves:

- K:1.0519 C-L-t (cruise) 4.9475
- k:0.6820 C-L-t (app) 4.9530
- Ù:0.71

### Vertical Tail Lift Curves:

- K:1.0366 C-L-e (cruise) 2.0802
- k:0.68 C-L-e (app) 2.2314
- Ù:0.71
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>V.T. c/2 Sweep rad</td>
<td>0.687</td>
</tr>
<tr>
<td>V.T. Taper Ratio</td>
<td>0.330</td>
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<tr>
<td>V.T. Moment Rms l-v</td>
<td>30.060</td>
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<tr>
<td>Approach Alpha a (rad)</td>
<td>0.1745</td>
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<tr>
<td>Approach l-v</td>
<td>31.41</td>
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<td>1+ (ds/d8)</td>
<td>1.477</td>
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<tr>
<td>Engine Mounting Bar:</td>
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<tr>
<td>Bar Area sqft</td>
<td>165.800</td>
</tr>
<tr>
<td>Bar Span ft</td>
<td>15.700</td>
</tr>
<tr>
<td>Bar MRC ft</td>
<td>10.620</td>
</tr>
<tr>
<td>Bar Aspect Ratio</td>
<td>1.467</td>
</tr>
<tr>
<td>Bar LE Sweep rad</td>
<td>0.436</td>
</tr>
<tr>
<td>Bar c/2 Sweep rad</td>
<td>0.314</td>
</tr>
<tr>
<td>Bar Taper Ratio</td>
<td>0.014</td>
</tr>
<tr>
<td>X-bar ac-h</td>
<td>1.794</td>
</tr>
<tr>
<td>1 - downwash</td>
<td>1.000</td>
</tr>
<tr>
<td>Bar q-bar corr. (eta-h)</td>
<td>1.000</td>
</tr>
<tr>
<td>Total Take-off Thrust lbs</td>
<td>37,891</td>
</tr>
<tr>
<td>Total Cruise Thrust (lbs)</td>
<td>4,414</td>
</tr>
<tr>
<td>Z-T (vertical mom. arm)</td>
<td>5.330</td>
</tr>
<tr>
<td>Y-T (horizontal mom. arm)</td>
<td>10.000</td>
</tr>
<tr>
<td>Non-dim. Derivatives: Cruise-fwd</td>
<td></td>
</tr>
<tr>
<td>C-L celebrated Airplane</td>
<td>6.533</td>
</tr>
<tr>
<td>C-m celebrated Airplane</td>
<td>-2.167</td>
</tr>
<tr>
<td>C-L-e-dot</td>
<td>3.146</td>
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<tr>
<td>C-m-e-dot</td>
<td>-13.474</td>
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<tr>
<td>C-m-q</td>
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<tr>
<td>C-y-e</td>
<td>-1.027</td>
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<tr>
<td>C-n-e</td>
<td>0.071</td>
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<tr>
<td>C-y-r</td>
<td>0.401</td>
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<tr>
<td>C-n-r</td>
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<td>Dimensional Derivatives: Cruise-fwd</td>
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<td>Z-e</td>
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<tr>
<td>Z-e-dot</td>
<td>-1.953</td>
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<tr>
<td>N-e</td>
<td>-5.436</td>
</tr>
<tr>
<td>N-e-dot</td>
<td>-0.258</td>
</tr>
<tr>
<td>N-q</td>
<td>-1.340</td>
</tr>
</tbody>
</table>

| Engine Bar Lift Curves:        |        |
| K:1.0278                       | C-L-e (cruise) 1.9622 |
| k:0.68                         | C-L-e (app) 1.9824  |
| @:0.71                         |
### Short Period

<table>
<thead>
<tr>
<th></th>
<th>Frequency</th>
<th>Damping Ratio</th>
<th>N+o</th>
<th>N-r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y-o</td>
<td>2.785</td>
<td>0.452</td>
<td>19.577</td>
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<tr>
<td>Y-r</td>
<td>2.559</td>
<td>0.640</td>
<td>32.860</td>
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<tr>
<td>N-o</td>
<td>1.492</td>
<td>0.639</td>
<td>4.566</td>
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<tr>
<td>N-r</td>
<td>1.534</td>
<td>0.736</td>
<td>7.664</td>
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</tbody>
</table>

### Dutch Roll

<table>
<thead>
<tr>
<th></th>
<th>Frequency</th>
<th>Damping Ratio</th>
<th>Omega + Zeta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y-o</td>
<td>1.025</td>
<td>0.131</td>
<td>0.134</td>
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<tr>
<td>Y-r</td>
<td>1.301</td>
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<td>0.220</td>
</tr>
<tr>
<td>N-o</td>
<td>0.577</td>
<td>0.202</td>
<td>0.117</td>
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<tr>
<td>N-r</td>
<td>0.736</td>
<td>0.250</td>
<td>0.191</td>
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</tbody>
</table>

### 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:

<table>
<thead>
<tr>
<th>C-y-4-r</th>
<th>C-ir-4-r</th>
<th>Required 4-r (rad)</th>
<th>Required 4-r (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.324</td>
<td>0.077</td>
<td>0.391</td>
<td>22.418</td>
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### Lift and Pitching Moment Calculations:

<table>
<thead>
<tr>
<th>Airplane X-ac (cruise)</th>
<th>0.591</th>
<th>Airplane X-ac (approach)</th>
<th>0.982</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airplane C-L-i (cruise)</td>
<td>6.533</td>
<td>Airplane C-L-i (approach)</td>
<td>6.595</td>
</tr>
<tr>
<td>Airplane C-M-s (cruise)</td>
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<td>Forward C.G.</td>
<td>-2.167</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aft C.G.</td>
<td>-1.233</td>
</tr>
<tr>
<td>Airplane C-M-s (approach)</td>
<td></td>
<td>Forward C.G.</td>
<td>-2.131</td>
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<tr>
<td></td>
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<td>Aft C.G.</td>
<td>-1.188</td>
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<td>C-L-i-H (cruise)</td>
<td>1.715</td>
<td>C-L-i-H (approach)</td>
<td>1.718</td>
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<tr>
<td>C-L-6-e (cruise)</td>
<td>0.927</td>
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</tbody>
</table>
### Lift Curve Equations

<table>
<thead>
<tr>
<th>Condition</th>
<th>C-l-o</th>
<th>C-l-h</th>
<th>C-l-i</th>
<th>C-l-flaps</th>
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</thead>
<tbody>
<tr>
<td>Cruise</td>
<td>0.170</td>
<td>0.114</td>
<td>0.030</td>
<td>0.015</td>
</tr>
<tr>
<td>Approach</td>
<td>0.170</td>
<td>0.115</td>
<td>0.030</td>
<td>0.015</td>
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</tbody>
</table>

### Pitching Moment Equations

<table>
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<tr>
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<th>C-o-o</th>
<th>C-l-o</th>
<th>C-l-h</th>
<th>C-l-i</th>
<th>C-l-flaps</th>
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<tr>
<td>Cruise-fwd</td>
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<td>-0.064</td>
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<td>Cruise-aft</td>
<td>0.100</td>
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<td>-0.118</td>
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<td>-0.010</td>
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<tr>
<td>Approach-fwd</td>
<td>0.109</td>
<td>-0.323</td>
<td>-0.119</td>
<td>-0.064</td>
<td>-0.290</td>
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<tr>
<td>Approach-aft</td>
<td>0.109</td>
<td>-0.180</td>
<td>-0.119</td>
<td>-0.064</td>
<td>-0.290</td>
</tr>
</tbody>
</table>

4C-o-o H.T. Forward C.G. 0.074
Aft C.G. 0.071
### Dynamic Pres. (psf)

<table>
<thead>
<tr>
<th>Speed (fps)</th>
<th>25</th>
<th>36</th>
<th>50</th>
<th>75</th>
<th>100</th>
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<td>Dynamic Pres. (psf)</td>
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<tr>
<td>Speed (fps)</td>
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### Wing Area and Span

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<thead>
<tr>
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<th>592</th>
<th>592</th>
<th>592</th>
<th>1182</th>
<th>1182</th>
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</thead>
<tbody>
<tr>
<td>Wing span</td>
<td>84.3</td>
<td>84.3</td>
<td>84.3</td>
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<td>132.5</td>
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### Handling Level

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<tr>
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### Delta-A (deg)

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APPENDIX E

ARAMID ALUMINUM DATA SUMMARY
Table of Contents

E.1 Properties E.3
E.2 Strengths E.3
E.3 Machinability E.3
E.4 Areas of Concern E.4
E.5 Most Likely Structural Component Uses E.4
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:**

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*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 factor 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 panel loading 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
REREFER TO SPEARESHEET:

\[ R = \frac{S_t}{S_E} \]

\[ C_{n_{SE}} (t+e) = C_{n_{SE}} + C_{n_{SE}} R \]

\[ \alpha_{TRIM} \quad \text{Eqn. 5.134} \]

\[ S_{o \text{TRIM}} \quad 5.135 \]

\[ \frac{d\alpha}{dC_L} = \frac{C_{m_{SE}}}{C_{L_{a}}C_{m_{SE}} - C_{m_a}C_{L_{SE}}} \]

\[ \frac{2\delta e}{2C_L} \quad \text{Eqn. 5.46} \]

\[ \alpha_{TRIM} \quad \text{Eqn. 5.132} \]

\[ S_{E_{TRIM}} \quad 5.133 \]

\[ C_h = C_{h_{a}} \alpha_{h} + C_{h_{a}} \alpha_{n} + C_{h_{SE}} \delta_{e} \quad \left( C_{h_{o}} = 0 \right) \]

\[ s_{M \text{FREE}} \quad \text{Eqn. 5.154} \]

\[ \frac{2F}{2n} \quad \text{Eqn. 5.163} \]

\[ \frac{2F}{2\nu} \quad 5.138 \]

\[ F_s = C \cdot H M \]

\[ \text{Note in Ref. 5} \]
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### 36 Pax Stick Force Calculations

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#### Geometries, Inertias

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#### Steady State Coefficients

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#### Longitudinal Derivatives

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#### Lateral-Directional Derivatives

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Longitudinal Stick Force Calculations

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### Longitudinal Stick Force Calculations

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**Eta-H**  
**Gearing Ratio (rad/ft)**  
**S-Elev. (ft)**  
**C-Elev. (ft)**  
**C-h-dE (rad-1)**  
**C-h-d-tab (rad-1)**  
**S-tab (ft)**  
**C-tab (ft)**  
**C-h-alpha (rad-1)**  
**1-H (ft)**  
**Tau-E**  
**i-H (deg)**  
**dE/da**  
**n/alpha (g/rad)**  
**n-Limit**  
**R (d-tab / d-elev.)**  
**C-h-de (tab + elev.)**  
**alpha-o-trim (rad)**  
**delta-o-trim (rad)**  
**d-alpha/dCL**  
**d-dE/dCL**  
**alpha-trim (rad)**  
**del-E-trim (rad)**  
**Load Factor (g's)**  
**d-dele/dv (rad/fps)**  
**d-dele/dn (rad/g)**  
**c-h**  
**S.M. (FREE)**  
**dF/dn (lbs/g)**  
**dF/dn MIN**  
**dF/dn MAX**  
**dF/dV (lbs/knot)**  
**F-S (lbs)**
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### 50 Pax Stick Force Calculations

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#### 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         |

#### Lateral-Directional Derivatives

<p>| 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            |</p>
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## Longitudinal Stick Force Calculations

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Longitudinal Stick Force Calculations

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75 Pax Baseline Stick Force Calculations

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Steady State Coefficients

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### Longitudinal Stick Force Calculations

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Longitudinal Stick Force Calculations

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### Lateral-Directional Derivatives

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Longitudinal Stick Force Calculations

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### Longitudinal Stick Force Calculations

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\tan \alpha' / 2 = \tan \alpha'' / 2 = \tan \beta / 2 = 0.231
\]

\[
\frac{t/c}{c_e/c} = 0.11 \quad \frac{c_e/c}{c_r/c} = 0.35
\]

\[
\frac{t/c}{c_a} = 0.13 \quad \frac{c_a}{c_r/c} = 0.3
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<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>(c_{h^\alpha,\text{theory}})</td>
<td>-0.57</td>
<td>-0.57</td>
<td>-0.54</td>
</tr>
<tr>
<td>(c_{h^\alpha,\text{theory}})</td>
<td>0.955</td>
<td>0.955</td>
<td>0.955</td>
</tr>
<tr>
<td>(c_{h^\alpha})</td>
<td>-0.513</td>
<td>-0.513</td>
<td>-0.486</td>
</tr>
<tr>
<td>(c_{h^\alpha,\text{theory}})</td>
<td>-0.445</td>
<td>-0.445</td>
<td>-0.429</td>
</tr>
<tr>
<td>(c_{h^\alpha})</td>
<td>0.08</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>(c_f)</td>
<td>0.27</td>
<td>0.27</td>
<td>0.22</td>
</tr>
<tr>
<td>(c_b)</td>
<td>0.08</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>(t/c )</td>
<td>0.26</td>
<td>0.26</td>
<td>0.39</td>
</tr>
<tr>
<td>(c_{h^\alpha,\text{BAL}} / c_{h^\alpha})</td>
<td>0.68</td>
<td>0.68</td>
<td>0.30</td>
</tr>
<tr>
<td>(c_{h^\alpha,\text{BAL}})</td>
<td>-0.303</td>
<td>-0.303</td>
<td>-0.129</td>
</tr>
<tr>
<td>VMC (m = 0.19)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c_{h^\alpha,\text{BAL}})</td>
<td>-0.424</td>
<td>-0.424</td>
<td>-0.181</td>
</tr>
<tr>
<td>CRUSEM (m = 0.7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reaction</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
|----------|----------
<p>| Ch6/Ch8 |<br />
|
| Ch8 |<br />
| Theory |<br />
| Ch6/Ch8 |<br />
| Theory |<br />
| Ch6 |<br />
| Theory |<br />
| Ch6 |<br />
| Theory |<br />
| Ch6 |<br />
| Balance |<br />
| Ch6 |<br />
|
| Ch8 |<br />
| Balance |<br />
| Ch6 |<br />
|
| Ch8 |<br />
| Balance |<br />
| Ch6 |<br />
|</p>
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<th>V-T</th>
<th>AIC</th>
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</thead>
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<tr>
<td>Ch6/Ch8 Theory</td>
<td>.95</td>
<td>.95</td>
<td>.95</td>
</tr>
<tr>
<td>Ch8 Theory</td>
<td>- .90</td>
<td>- .90</td>
<td>- .85</td>
</tr>
<tr>
<td>Ch6</td>
<td>- .855</td>
<td>- .855</td>
<td>- .808</td>
</tr>
<tr>
<td>Ch6/Ch8 Theory</td>
<td>.92</td>
<td>.92</td>
<td>.92</td>
</tr>
<tr>
<td>Ch8 Theory</td>
<td>4.8</td>
<td>4.8</td>
<td>4.5</td>
</tr>
<tr>
<td>Ch6</td>
<td>- .778</td>
<td>- .778</td>
<td>- .736</td>
</tr>
<tr>
<td>Ch6 Balance</td>
<td>.6</td>
<td>.6</td>
<td>.2</td>
</tr>
<tr>
<td>Ch8 Balance</td>
<td>- .467</td>
<td>- .467</td>
<td>- .147</td>
</tr>
<tr>
<td>Ch6 Balance</td>
<td>- .654</td>
<td>- .654</td>
<td>- .206</td>
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M = .19

M = .7
<table>
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<th>ALL</th>
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<tr>
<td>$C_{h\alpha}$</td>
<td>-0.30</td>
<td>-0.30</td>
<td>-0.13</td>
</tr>
<tr>
<td>$C_{h\beta}$</td>
<td>-0.42</td>
<td>-0.42</td>
<td>-0.18</td>
</tr>
<tr>
<td>$C_{h\gamma}$</td>
<td>-0.47</td>
<td>-0.47</td>
<td>-0.15</td>
</tr>
<tr>
<td>$C_{h\delta}$</td>
<td>-0.65</td>
<td>-0.65</td>
<td>-0.21</td>
</tr>
</tbody>
</table>
For 25 Pax 400 F.S.
For 36 Pax 530 F.S.
For 50 Pax 600 F.S.

STANDARD
4 x 3\(\frac{3}{4}\) x 5\(\frac{1}{2}\) Angle
(AREA = 4.30 in\(^2\))

Note: Airfoil similar to HSNLF (1) - 0213

Figure 3.1 - Wing Cross Section
\[ C_{\alpha} = \frac{A \cos \frac{\Lambda_{c}}{4}}{A + 2 \cos \frac{\Lambda_{c}}{4}} \quad C_{\alpha_{\text{BAL}}} + \Delta C_{\alpha} \]

<table>
<thead>
<tr>
<th></th>
<th>H-T</th>
<th>V-T</th>
<th>A-I-L</th>
<th>T-B</th>
<th>T-D</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5.68</td>
<td>1.7</td>
<td>12</td>
<td>13.6</td>
<td>17.54</td>
</tr>
<tr>
<td>(\Lambda_{c}/4)</td>
<td>20.8°</td>
<td>42.0°</td>
<td>12°</td>
<td>4.3°</td>
<td>10°</td>
</tr>
<tr>
<td>(K_{\alpha})</td>
<td>1.0</td>
<td>1.0</td>
<td>3.02</td>
<td>1.0</td>
<td>3.44</td>
</tr>
<tr>
<td>(\Delta C_{\alpha_{\text{BAL}}}/I)</td>
<td>0.007</td>
<td>0.015</td>
<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
</tr>
<tr>
<td>(B_{2})</td>
<td>0.98</td>
<td>0.98</td>
<td>0.93</td>
<td>0.98</td>
<td>0.93</td>
</tr>
<tr>
<td>(\Delta C_{\alpha})</td>
<td>0.038</td>
<td>0.068</td>
<td>0.66</td>
<td>0.023</td>
<td>0.076</td>
</tr>
<tr>
<td>(C_{\alpha_{\text{BAL}}})</td>
<td>-0.303</td>
<td>-0.303</td>
<td>-0.129</td>
<td>-0.303</td>
<td>-0.129 (VH)</td>
</tr>
<tr>
<td>(Q_{\alpha_{\text{BAL}}})</td>
<td>-0.424</td>
<td>-0.424</td>
<td>-0.181</td>
<td>-0.424</td>
<td>-0.181 (Clue)</td>
</tr>
<tr>
<td>(A \cos \Lambda_{c}/4)</td>
<td>0.709</td>
<td>0.366</td>
<td>0.838</td>
<td>0.870</td>
<td>0.869</td>
</tr>
<tr>
<td>(A + 2 \cos \Lambda_{c}/4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ A \cos \Lambda_{c}/4 \] \[ A + 2 \cos \Lambda_{c}/4 \]
\[ \alpha_s = -\frac{(C_{eo})_o}{(C_{eo})_s} \]

\[ C_{eo}/C = 0.35 \]

\[ C_{eo} = 0.77 \text{ deg}^{-1} = 4.412 \text{ rad}^{-1} \]

\[ C_{e\alpha} = 6.0 \text{ rad}^{-1} \]

\[ \alpha_s = -0.735 \]

\[ \Delta C_{h_s} = \frac{\Delta C_{h_s}}{C_{e\alpha}} \left( \frac{C_{eo} B_2 K_s \cos \lambda_{44} \cos \lambda_{HL}}{C_{eo} B_2 K_s \cos \lambda_{44} \cos \lambda_{HL}} \right) \]

<table>
<thead>
<tr>
<th>25 Pax</th>
<th>36 Pax</th>
<th>50 Pax</th>
<th>75 Pax</th>
<th>100 Pax</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ A_h ]</td>
<td>5.883</td>
<td>5.883</td>
<td>13.60</td>
<td>13.60</td>
</tr>
</tbody>
</table>

\[ \Delta C_{h_s} = \frac{\Delta C_{h_s}}{A_h} \]

\[ B_2 = 0.93 \]

\[ K_s = \left( K_s \right) \eta_i \left( 1 - \eta_i \right) - \left( K_s \right) \eta_o \left( 1 - \eta_o \right) \]

\[ \eta_i = 0, \quad \eta_o = 1 \]

\[ K_s = 1.0 \]

\[ \lambda_{eo/HL} = 0.364 \]

\[ \lambda_{HL} = 0.349 \]

\[ I \{ \}

\[ \Delta C_{h_s} = 0.000693 \]

\[ \Delta C_{h_s} = 0.0396 \]

\[ C_{HSE} = 0 \left( \lambda_{HL} \right) \cos \lambda_{HL} \left[ \left( C_{h_4} \right)_{bal} + \alpha_s \left( C_{h_4} \right)_{bal} \frac{2 \cos \lambda_{44}}{A + 2 \cos \lambda_{44}} \right] + \Delta C_{h_s} \]

<table>
<thead>
<tr>
<th>[ C_{HSE} \text{ Vmc} ]</th>
<th>[ C_{HSE} \text{ Cruise} ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.323</td>
<td>-0.469</td>
</tr>
<tr>
<td>-0.323</td>
<td>-0.469</td>
</tr>
<tr>
<td>-0.323</td>
<td>-0.469</td>
</tr>
<tr>
<td>-0.422</td>
<td>-0.598</td>
</tr>
<tr>
<td>-0.422</td>
<td>-0.598</td>
</tr>
</tbody>
</table>

\[ \text{(rad)} \]

\[ \text{(deg)} \]

\[ \text{(rad)} \]

\[ \text{(deg)} \]
\[ \frac{c_R}{c} = 0.35 \quad \text{and} \quad \frac{c_b}{c_R} \approx 0.3 \]

Fig. 6.1.1.1-42 \[ C_{d_\delta} = 0.077 \, \text{deg}^{-1} = 4.412 \, \text{rad}^{-1} \]

\[ C_{d\alpha} = 6.0 \, \text{rad}^{-1} \]

\[ \alpha_\delta = -7.35 \]

\[
\begin{array}{cccccc}
\text{25 Pax} & \text{36 Pax} & \text{50 Pax} & \text{75 Pax} & \text{100 Pax} \\
\hline
A_{\text{WT}} & 1.4 & 1.4 & 1.4 & 1.4 & 1.4 \\
\frac{D C_{d\delta}}{(I)} & 0.025 & 0.025 & 0.025 & 0.025 & 0.025 \\
\text{Fig. 6.1.6.2-15} & \text{Fig. 6.1.6.1-19c} & B_2 = 0.98 & & & \\
K_{e_R} = 1.0 & & & & & \\
\Lambda_{\text{W}} = 7.0 \, \text{rad} & & & & & \\
\Lambda_{\text{HLL}} = 4.36 \, \text{rad} & & & & & \\
I & 3.059 & 3.059 & 3.059 & 3.059 & 3.059 & (\text{rad}^{-1}) \\
\Delta C_{d\delta} & 0.0765 & 0.0765 & 0.0765 & 0.0765 & 0.0765 & (\text{rad}^{-1}) \\
C_{d\delta} V_{\text{mc}} & -0.167 & -0.167 & -0.167 & -0.167 & -0.167 & (\text{rad}^{-1}) \\
C_{d\delta} \text{ Cruise} & -0.250 & -0.250 & -0.250 & -0.250 & -0.250 & (\text{rad}^{-1}) \\
\end{array}
\]
\[ \frac{C_A}{c} = 0.30 \quad \frac{C_B}{C_A} \approx 0.3 \]

Fig. 6.1.1-42  
\[ C_{pA} = 0.072 \, \text{deg}^{-1} = 4.125 \, \text{rad}^{-1} \]
\[ C_{pA} = 6.0 \, \text{rad}^{-1} \]
\[ \alpha_0 = -0.686 \]

<table>
<thead>
<tr>
<th></th>
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<th>36 Pax.</th>
<th>50 Pax.</th>
<th>75 Pax.</th>
<th>100 Pax.</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A_w )</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
<td>14.843</td>
<td>14.843</td>
</tr>
<tr>
<td>( \frac{\Delta C_{\text{th}}}{(I)} )</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>Fig 6.1.6.2-15 ( B_e = 0.93 )</td>
<td>0.950</td>
<td>0.950</td>
<td>0.950</td>
<td>0.906</td>
<td>0.906</td>
</tr>
<tr>
<td>( \eta_1 )</td>
<td>0.968</td>
<td>0.968</td>
<td>0.968</td>
<td>0.981</td>
<td>0.981</td>
</tr>
<tr>
<td>( \phi_0 )</td>
<td>3.25</td>
<td>3.25</td>
<td>3.25</td>
<td>3.44</td>
<td>3.44</td>
</tr>
<tr>
<td>( \eta_0 )</td>
<td>3.02</td>
<td>3.02</td>
<td>3.02</td>
<td>3.44</td>
<td>3.44</td>
</tr>
<tr>
<td>( \eta_0 )</td>
<td>0.228</td>
<td>0.228</td>
<td>0.228</td>
<td>0.177</td>
<td>0.177</td>
</tr>
<tr>
<td>( \eta_0 )</td>
<td>0.175</td>
<td>0.175</td>
<td>0.175</td>
<td>0.128</td>
<td>0.128</td>
</tr>
<tr>
<td>( I )</td>
<td>11.11</td>
<td>11.11</td>
<td>11.11</td>
<td>12.88</td>
<td>12.88</td>
</tr>
<tr>
<td>( \Delta C_{\text{he}} )</td>
<td>0.056</td>
<td>0.056</td>
<td>0.056</td>
<td>0.059</td>
<td>0.059</td>
</tr>
<tr>
<td>( C_{\text{he}} )</td>
<td>-0.073</td>
<td>-0.073</td>
<td>-0.073</td>
<td>-0.094</td>
<td>-0.094</td>
</tr>
<tr>
<td>( C_{\text{he}} )</td>
<td>-0.125</td>
<td>-0.125</td>
<td>-0.125</td>
<td>-0.148</td>
<td>-0.148</td>
</tr>
</tbody>
</table>
Reference Datacom section 6.1.3.3

\[
\begin{align*}
\left( \frac{\partial C_{1f}}{\partial \delta_t} \right)_{\alpha, \delta_f} &= A = -0.015, \quad C_{1f}/C_f = 0.35 \\
\left( \frac{\partial C_{1f}}{\partial \delta_t} \right)_{\delta_t, \delta_f} &= B = -0.067 \\
\left( \frac{\partial C_{1f}}{\partial \alpha} \right)_{\delta_t, \delta_f} &= C = 0.105 = C_{1f} \\
\left( \frac{\partial C_{1f}}{\partial \delta_f} \right)_{\alpha, \delta_f} &= D = -0.730
\end{align*}
\]

\[
C_{sh_t} = \left( \frac{\partial C_{1f}}{\partial \delta_t} \right)_{\alpha, \delta_f}
\]

\[
C_{sh_t} = A - BCD
\]

\[
C_{sh_{\delta t}} = -0.020 \ \text{deg}^{-1}
\]

\[
C_{sh_{\gamma t}} = -1.154 \ \text{rad}^{-1}
\]
SECTIONAL $C_{h_{\alpha}}$ FOR TRIM TAB

$C_{h_{\alpha}} = -0.445 \text{ rad}^2$ (NO BALANCE EFFECTS)

AT $M = 0.7$

$C_{h_{\alpha}} = -0.623 \text{ rad}^2$
\[ C_{ht} = (\cos \lambda_{c/4} \cos \lambda_{H/L}) (H \cdot M) + \Delta C_{ht} \]

\[ H \cdot M = C_{ht} + \kappa \varepsilon C_{ht} \frac{2 \cos \lambda_{c/N}}{A + 2 \cos \lambda_{c/N}} \]

\begin{tabular}{|c|c|c|}
\hline
& H.T & V.T \\
\hline
\Delta C_{ht} & 0.01 & 0.03 \\
\kappa & 1.0 & 1.1 \\
\lambda_{c/4} & 0.75 & 0.75 \\
\cos \lambda_{c/4} \cos \lambda_{H/L} & 0.83 & 0.60 \\
\hline
\end{tabular}

\[
\kappa_i = 0.4 \quad \kappa_0 = 0.8
\]

\[ \Delta \lambda_{c/4} \]

\[ \lambda_{c/4} = 0.364 \quad 0.70 \]

\[ A = 5.88 \quad 1.7 \]
\( C_{n} \) \text{ based on } S_t, c_t

\begin{align*}
V_{H,T} & : -1.003 \\
V_{V,T} & : -0.754 \\
C & : -1.022 \\
c_0 & : -0.784
\end{align*}

\( n_i = .4 \)  \\
\( n_o = .8 \) \\
\( c_t/c_e = .35 \)
Appendix G
Component Drag Calculations

Purpose: This appendix contains drag calculations following methods in Reference 13.
\[ C_{D_{\text{wing}}} = C_{D_{\text{sw}}} + C_{D_{\text{LW}}} \quad (\text{NLF considerations}) \]
\[ + C_{D_{\text{sw}}} = (K_{w}p)(\text{C}_{L})[1 + (\text{L}'(\text{C}) + 100(\text{C}))^4] \left[ (C_{f_{\text{swlum}}} - C_{f_{\text{swlur}}}) \text{Sw}_{\text{swlum}} + \right] \]
\[ + (C_{f_{\text{swl}}} \text{Sw}_{\text{swl}}) \frac{1}{S} \quad \text{M_{\text{cruise}} = 0.7} \]
\[ \text{M_{\text{app}} = 0.15} \]
\[
\begin{array}{|c|c|c|c|c|c|}
\hline
\text{S}_{\text{swlum}} & \text{S}_{\text{swlur}} & \text{S}_{\text{swl}} \\hline
25 \text{Pax} & 36 \text{Pax} & 50 \text{Pax} & 75 \text{Pax} & 100 \text{Pax} \\hline
\text{\text{L}'} & 1.2 \quad 1.2 \quad 1.2 \quad 1.2 \quad 1.2 \\hline
\text{\text{S}_{\text{swlum}}} & 114 & 114 & 114 & 224 & 224 \\hline
\text{\text{S}_{\text{swlur}}} & 592 & 592 & 592 & 1182 & 1182 \\hline
\text{\text{C}_{f_{\text{swlum}}}} & 0.00255 & 0.00294 \\hline
\end{array}
\]
\[ \text{\text{R}_{\text{Nw}}(\text{swlum})} = 2.2 \times 10^7 \quad \text{\text{R}_{\text{Nw}}(\text{swlur})} = 1.2 \times 10^7 \]
\[ \text{\text{R}_{\text{Nw}}(\text{swl})} = 5.5 \frac{\text{ft}}{\text{f}} \quad (50 \%) \]
\[ \text{\text{R}_{\text{Nw}}(\text{swlum})} = 1.1 \times 10^7 \quad \text{\text{R}_{\text{Nw}}(\text{swlur})} = 0.6 \times 10^7 \]
\[ \text{\text{C}_{f_{\text{swlum}}}} = 0.004 \quad \text{\text{C}_{f_{\text{swlur}}}} = 0.0005 \]
\[ (\text{\text{f}^2) \quad (\text{\text{f}^2})} \]
<table>
<thead>
<tr>
<th></th>
<th>WING</th>
<th>DRAG POLAR</th>
<th>R. HADDAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>S_wet, \text{ wam}</td>
<td>\text{582}</td>
<td>\text{582}</td>
<td>\text{582}</td>
</tr>
<tr>
<td>C_{D_{w,\text{cruise}}}</td>
<td>\text{0.0042}</td>
<td>\text{0.0042}</td>
<td>\text{0.0042}</td>
</tr>
<tr>
<td>C_{D_{w,\text{app}}}</td>
<td>\text{0.0040}</td>
<td>\text{0.0040}</td>
<td>\text{0.0040}</td>
</tr>
</tbody>
</table>

\[ C_{D_{L_w}} = \left( \frac{C_{L_w}}{\pi A_e} \right)^2 + \frac{4 \pi^2}{\pi} C_{L_w} \frac{e}{V} + 4 \pi^2 \left( \frac{e}{V} \right)^2 \]

\[ C_{L_w} = 1.05 \quad C_L = 1.05 \left( \frac{W}{A} \right) \]

\[ e = 1.1 \left( \frac{C_{L_w}}{A} \right) \left[ R \left( \frac{C_{L_w}}{A} \right) + (1-R) \pi \right] \]

\[ C_{L_w,\text{cruise}} = 4.7089 \quad 4.7089 \quad 4.7087 \quad 4.9077 \quad 4.9077 \quad (\text{rd}) \]
\[ C_{L_w,\text{app}} = 4.7794 \quad 4.7794 \quad 4.7794 \quad 4.9673 \quad 4.9673 \quad (\text{rd}) \]

\[ \kappa = 1.0 \left( \frac{R}{\ell} \right) ; \quad \lambda = .4 \]

\[ R_{\text{cruise}} = R_{\text{app}} = R_{\text{cruise}} = 0.00 \times 10^6 \]

<table>
<thead>
<tr>
<th></th>
<th>2500 ft</th>
<th>3600 ft</th>
<th>5000 ft</th>
<th>7500 ft</th>
<th>10000 ft</th>
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<tr>
<td>( A_{LE} )</td>
<td>\text{0.262}</td>
<td>\text{0.262}</td>
<td>\text{0.262}</td>
<td>\text{0.201}</td>
<td>\text{0.201}</td>
</tr>
<tr>
<td>A</td>
<td>\text{12.0}</td>
<td>\text{12.0}</td>
<td>\text{12.0}</td>
<td>\text{14.84}</td>
<td>\text{14.84}</td>
</tr>
<tr>
<td>Fig 4.7</td>
<td>R</td>
<td>\text{0.960}</td>
<td>\text{0.960}</td>
<td>\text{0.960}</td>
<td>\text{0.965}</td>
</tr>
<tr>
<td></td>
<td>25 Pax</td>
<td>36 Pax</td>
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<td>--------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>A</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
<td>14.84</td>
<td>14.84</td>
</tr>
<tr>
<td>( \alpha_{\text{cruise}} )</td>
<td>8.59</td>
<td>8.59</td>
<td>8.59</td>
<td>8.48</td>
<td>8.48</td>
</tr>
<tr>
<td>( \alpha_{\text{app}} )</td>
<td>8.62</td>
<td>8.62</td>
<td>8.62</td>
<td>8.94</td>
<td>8.94</td>
</tr>
<tr>
<td>( T \alpha_{\text{cruise}} )</td>
<td>32.38</td>
<td>32.38</td>
<td>32.38</td>
<td>39.53</td>
<td>39.53</td>
</tr>
<tr>
<td>( T \alpha_{\text{app}} )</td>
<td>32.50</td>
<td>32.50</td>
<td>32.50</td>
<td>41.68</td>
<td>41.68</td>
</tr>
</tbody>
</table>

It is assumed that the twist angle \( \alpha_t = 1^\circ = 0.0174 \). 

<table>
<thead>
<tr>
<th>Fig 4.9(a)</th>
<th>V</th>
<th>0.0009</th>
<th>0.0009</th>
<th>0.0009</th>
<th>0.0008</th>
<th>0.0008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig 4.10(a)</td>
<td>W</td>
<td>0.0003</td>
<td>0.0003</td>
<td>0.0003</td>
<td>0.0003</td>
<td>0.0003</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
C_{D_{\text{LW,cruise}}} & = 0.0017 \\
C_{D_{\text{LW,app}}} & = 0.0666 \\
\text{then} & \\
C_{D_{\text{wing,cruise}}} & = 0.0059 \\
C_{D_{\text{wing,app}}} & = 0.0706
\end{align*}
\]

\[
\begin{align*}
C_{D_{\text{wing,cruise}}} & = 0.0069 \\
C_{D_{\text{wing,app}}} & = 0.0081 \\
C_{D_{\text{wing,cruise}}} & = 0.0062 \\
C_{D_{\text{wing,app}}} & = 0.0071
\end{align*}
\]
\[ C_{D_{ fus}} = C_{D_{ fus}} + C_{D_{ b fus}} \]

\[ C_{D_{ fus}} = \frac{R_{W P}}{5} \left[ 1 + \frac{60 \left( \frac{d \chi}{d \phi} \right)^3}{(\frac{\rho_f}{\rho})^2} \right] \left[ (C_{D_{ fus, lam}} + C_{D_{ fus, lam}}) S_{Wet, lam} + C_{D_{ fus, lam}} S_{Wet, lam} \right] + C_{D_{ b fus}} \]

<table>
<thead>
<tr>
<th>( R_{W P} )</th>
<th>25 Pax</th>
<th>36 Pax</th>
<th>50 Pax</th>
<th>75 Pax</th>
<th>100 Pax</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \phi )</td>
<td>69.4</td>
<td>78.1</td>
<td>94.6</td>
<td>78.1</td>
<td>94.6</td>
</tr>
<tr>
<td>( R_{N fus} )</td>
<td>1.38 \times 10^8</td>
<td>1.55 \times 10^8</td>
<td>1.87 \times 10^8</td>
<td>1.55 \times 10^8</td>
<td>1.38 \times 10^8</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>1.015</td>
<td>1.015</td>
<td>1.015</td>
<td>1.015</td>
<td>1.015</td>
</tr>
<tr>
<td>( C_{D_{ fus}} )</td>
<td>.0019</td>
<td>.0019</td>
<td>.00185</td>
<td>.0019</td>
<td>.00185</td>
</tr>
<tr>
<td>( d_f = 8.05 \text{ ft} )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( S_{Wet} )</td>
<td>450</td>
<td>506</td>
<td>651</td>
<td>2(506)</td>
<td>2(506)</td>
</tr>
<tr>
<td>( R_{N fus, lam} = \left( \frac{R_{N fus}}{\rho \frac{\rho_{lam}}{\rho}} \right) )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( l_{lam} = 12.5 \text{ ft} )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( R_{N fus, lam} = 2.49 \times 10^7 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( C_{D_{ fus, lam}} = 1.33 \left( \sqrt{R_{N fus, lam}} \right)^{-1} )</td>
<td>0.0027</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( S_{Wet, fus, lam} = 101 \text{ ft}^2 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( C_{D_{ fus, lam}} = 0 ) because of the lack of base.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| \( C_{D_{ fus}} \) | 0.00191 | 0.00148 | 0.00191 | 0.00148 | 0.00191 |
\[ C_{D_{\text{ fus}}} = 2 \alpha^2 \frac{S_{\text{ fus}}}{S} + \eta C_{d_c} \frac{\alpha^3 S_{\text{ fus}}}{S} \]

\[ \alpha = \left[ \frac{W}{q_S} - C_{L_{\infty}} \right] \frac{1}{C_{L_{\infty}}} \]

\[ C_{L_{\text{cruise}}} = C_{L_{\text{approach}}} = 0.17 \]

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>( C_{L_{\text{cruise}}} )</td>
<td>5.479</td>
<td>5.922</td>
<td>6.424</td>
<td>6.249</td>
</tr>
<tr>
<td>( C_{L_{\text{approach}}} )</td>
<td>5.565</td>
<td>5.507</td>
<td>6.476</td>
<td>6.311</td>
</tr>
<tr>
<td>( \alpha_{\text{cruise}} )</td>
<td>0.0077</td>
<td>0.0309</td>
<td>0.0172</td>
<td>0.0262</td>
</tr>
<tr>
<td>( \alpha_{\text{approach}} )</td>
<td>0.0096</td>
<td>0.0305</td>
<td>0.0170</td>
<td>0.0259</td>
</tr>
</tbody>
</table>

\( S_{\text{ fus}} = 0.5 \text{ ft}^2 \)

\( d_f = 96.6'' = 8.05 \text{ ft} \)

\[ \eta = 0.670 \quad 0.685 \quad 0.705 \quad 0.705 \]

\[ C_{d_c} = 1.2 \quad 1.2 \quad 1.2 \quad 1.2 \]

\[ S_{\text{ fus}} = 490 \quad 553 \quad 698 \quad 2(553) \quad 2(658) \quad \text{(ft}^2) \]

\[ C_{D_{\text{ fus}}} = 0.0000 \quad 0.0000 \quad 0.0001 \quad 0.0001 \quad 0.0001 \]

\[ C_{D_{\text{ fus}}(\text{cruise})} = 0.0000 \quad 0.0000 \quad 0.0001 \quad 0.0001 \quad 0.0001 \]

\[ C_{D_{\text{ fus}}(\text{approach})} = 0.0000 \quad 0.0000 \quad 0.0001 \quad 0.0001 \quad 0.0001 \]

\[ \text{then} \quad C_{D_{\text{ fus}}} = 0.0019 \quad 0.0015 \quad 0.0020 \quad 0.0015 \quad 0.0020 \]

Windshield drag is negligible and is accounted for in the fuselage drag. \( \rightarrow C_{D_{\text{dw}}} = 0 \)
\[ C_{D_{HT}} = C_{D_{0,HT}} + C_{D_{L,HT}} \]

\[ C_{D_{0,HT}} = (R_{Ls}) \left[ 1 + L' \left( \frac{T}{c} \right) + 100 \left( \frac{T}{c} \right)^{4} \right] \left[ (C_{l}^{*}_{HT,\text{air}} - C_{l}^{*}_{HT,\text{air}}) S_{\text{HT,air}} \right] + \frac{C_{p}^{*}_{HT} S_{\text{HT,air}}}{S} \]

\[ \text{Hence} = 0.7 \]
\[ \text{Mapp} = 0.15 \]

<table>
<thead>
<tr>
<th>25 Pax</th>
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</tr>
</thead>
<tbody>
<tr>
<td>( \lambda_{HT,\text{cruise}} )</td>
<td>0.314</td>
<td>0.314</td>
<td>0.314</td>
<td>0.052</td>
</tr>
<tr>
<td>( R_{Ls,\text{cruise}} )</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.21</td>
</tr>
<tr>
<td>( R_{Ls,\text{app}} )</td>
<td>1.07</td>
<td>1.07</td>
<td>1.07</td>
<td>1.08</td>
</tr>
</tbody>
</table>

\[ R_{NHT} = \frac{U_{1}}{C_{HT} \sqrt{\mu}} \]

Cruise \[ \rho = 0.8893 \times 10^{-3} \frac{\text{slug}}{\text{ft}^{3}} ; \quad \mu = 3.106 \times 10^{-7} \frac{\text{slug}}{\text{ft}^{3}} ; \quad U_{1} = 696.29 \frac{\text{ft}}{\text{s}} \]

Approach \[ \rho = 2.377 \times 10^{-3} \frac{\text{slug}}{\text{ft}^{3}} ; \quad \mu = 3.73 \times 10^{-6} \frac{\text{slug}}{\text{ft}^{3}} ; \quad U_{1} = 167.46 \frac{\text{ft}}{\text{s}} \]

\[ C_{HT,\text{cruise}} = 0.00280 \]
\[ C_{HT,\text{app}} = 0.00321 \]

\[ L' = 1.2 \]
\[ \mu = 0.13 \]
\[ S_{\text{HT,air}} = 200 \quad 200 \quad 200 \quad 780 \quad 780 \quad (\text{ft}) \]
\[ S = 592 \quad 592 \quad 592 \quad 1182 \quad 1182 \quad (\text{ft}) \]

\[ C_{HT,\text{app}} = 1.33 \left( \sqrt{R_{HT,\text{air}}} \right)^{-1} \]

\[ R_{HT,\text{air}} = \frac{U_{1} C_{HT,\text{cruise}}}{\mu} \]

\[ C_{HT,\text{cruise}} = 3.01 \frac{\text{ft}}{\text{s}} \quad (50\%) \]
\[ R_{\text{H.T.\,lam}} = 6.0 \times 10^6 \]
\[ R_{\text{H.T.\,lam}} = 3.21 \times 10^6 \]
\[ C_{p_{\text{H.T.\,lam\,cruise}}} = 5.43 \times 10^{-4} \]
\[ C_{p_{\text{H.T.\,lam\,app}}} = 7.43 \times 10^{-4} \]
\[ S_{\text{weH.T.\,lam}} = 0.5 \times (S_{\text{weH.T.}}) \]

<table>
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<th>75 Pax</th>
<th>100 Pax</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S_{\text{weH.T.,lam}} )</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>390</td>
<td>390 ((\text{ft}^2))</td>
</tr>
<tr>
<td>( C_{D_{\text{H.T.,cruise}}} )</td>
<td>0.00080</td>
<td>0.00080</td>
<td>0.00080</td>
<td>0.00160</td>
<td>0.00160</td>
</tr>
<tr>
<td>( C_{D_{\text{H.T.,app}}} )</td>
<td>0.00085</td>
<td>0.00085</td>
<td>0.00085</td>
<td>0.00167</td>
<td>0.00167</td>
</tr>
</tbody>
</table>

\[ C_{D_{\text{L.H.T.}}} = \left[ \frac{(C_{L_h})^2}{\pi A_h e_h} \right] \frac{S_h}{S} \]

\[ C_{L_h} = C_{L_{ox\,h}} \]
\[ C_{L_{ox\,h\,cruise}} = 3.6488 \]
\[ C_{L_{ox\,h\,app}} = 3.7569 \]
\[ \alpha_h = \alpha \left( 1 - \frac{d\epsilon}{d\alpha} \right) \]
\[ 1 - \frac{d\epsilon}{d\alpha} = 0.764 \]
\[ e_h = 0.75 \]
<table>
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<tr>
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<th>75 Pox</th>
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</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_{\text{cru}}$</td>
<td>0.0077</td>
<td>0.0204</td>
<td>0.0309</td>
<td>0.0172</td>
<td>0.0262</td>
</tr>
<tr>
<td>$\alpha_{\text{app}}$</td>
<td>0.0076</td>
<td>0.0201</td>
<td>0.0305</td>
<td>0.0170</td>
<td>0.0259</td>
</tr>
<tr>
<td>$\alpha_{\text{h.cru}}$</td>
<td>0.0074</td>
<td>0.0156</td>
<td>0.0236</td>
<td>0.0131</td>
<td>0.0200</td>
</tr>
<tr>
<td>$\alpha_{\text{h.app}}$</td>
<td>0.0073</td>
<td>0.0154</td>
<td>0.0233</td>
<td>0.0130</td>
<td>0.0198</td>
</tr>
<tr>
<td>$C_{L_{\text{h.cru}}}$</td>
<td>0.0270</td>
<td>0.0569</td>
<td>0.0861</td>
<td>0.0478</td>
<td>0.0729</td>
</tr>
<tr>
<td>$C_{L_{\text{h.app}}}$</td>
<td>0.0274</td>
<td>0.0579</td>
<td>0.0875</td>
<td>0.0488</td>
<td>0.0744</td>
</tr>
<tr>
<td>$A_{h}$</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>12.78</td>
<td>12.78</td>
</tr>
<tr>
<td>$S_{h}$</td>
<td>102</td>
<td>102</td>
<td>102</td>
<td>392</td>
<td>392</td>
</tr>
<tr>
<td>$S$</td>
<td>592</td>
<td>592</td>
<td>592</td>
<td>1182</td>
<td>1182</td>
</tr>
</tbody>
</table>

$\rightarrow C_{D_{L_{\text{h.cru}}}}$ = 0.00001, 0.00004, 0.00011, 0.00003, 0.00008

$\rightarrow C_{D_{L_{\text{h.app}}}}$ = 0.00001, 0.00005, 0.00011, 0.00003, 0.00008

then $C_{D_{\text{h.T.}}}$ = 0.0008, 0.0008, 0.0009, 0.0016, 0.0016
\[ C_{D_{V.T}} = C_{D_{0.V.T}} + C_{D_{L.V.T}} \]

But in this case \( C_{D_{L.V.T}} = 0 \)

\[ C_{D_{V.T}} = C_{D_{0.V.T}} \]

\[ C_{D_{0.V.T}} = \left( \frac{R_{LS}}{5} \right) \left[ 1 + L' \left( \frac{t}{c} \right) + 100 \left( \frac{t}{c} \right)^2 \right] \left( C_{p_{V.T \text{lam}}} - C_{p_{V.T \text{tur}}} \right) S_{\text{wet.V.T}} + \left( C_{p_{V.T \text{lam}} S_{\text{wet.V.T}}} \right) \frac{1}{3} \]

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<tbody>
<tr>
<td>( L_{V.T \text{max}} )</td>
<td>0.687</td>
<td>0.687</td>
<td>0.697</td>
<td>0.687</td>
<td>-0.687</td>
</tr>
<tr>
<td>( R_{L.S \text{cruise}} )</td>
<td>1.24</td>
<td>1.24</td>
<td>1.24</td>
<td>1.24</td>
<td>1.24</td>
</tr>
<tr>
<td>( R_{L.S \text{app}} )</td>
<td>1.02</td>
<td>1.02</td>
<td>1.02</td>
<td>1.02</td>
<td>1.02</td>
</tr>
<tr>
<td>( R_{N_{V.T \text{cruise}}} )</td>
<td>3.31 x 10^7</td>
<td>[ C_{p_{V.T \text{cruise}}} = ] 0.0024</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( R_{N_{V.T \text{app}}} )</td>
<td>1.77 x 10^7</td>
<td>[ C_{p_{V.T \text{app}}} = ] 0.0027</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( L' )</td>
<td>1.2</td>
<td>[ t/c = 0.13 ]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( S_{\text{wet.V.T}} )</td>
<td>340</td>
<td>340</td>
<td>340</td>
<td>680</td>
<td>680</td>
</tr>
<tr>
<td>( \bar{E}_{V.T \text{lam}} )</td>
<td>8.3 ft</td>
<td>(50%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( R_{N_{V.T \text{lam \text{cruise}}} \text{cruise}} )</td>
<td>1.65 x 10^7</td>
<td>[ C_{p_{\text{lam \text{cruise}}} = ] 3.27 x 10^-4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( R_{N_{V.T \text{lam \text{app}}} \text{app}} )</td>
<td>8.84 x 10^6</td>
<td>[ C_{p_{\text{lam \text{app}}} = ] 4.47 x 10^-4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( S_{\text{wet.V.T \text{lam}}} )</td>
<td>0.5 S_{\text{wet.V.T}}</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( S_{\text{wet.V.T \text{lam}}} )</td>
<td>170</td>
<td>170</td>
<td>170</td>
<td>340</td>
<td>340</td>
</tr>
<tr>
<td></td>
<td>25% Ax</td>
<td>36% Ax</td>
<td>50% Ax</td>
<td>75% Ax</td>
<td>100% Ax</td>
</tr>
<tr>
<td>----------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>$C_{D_{0v.t\text{ trim}}}$</td>
<td>0.0012</td>
<td>0.0012</td>
<td>0.0012</td>
<td>0.0012</td>
<td>0.0012</td>
</tr>
<tr>
<td>$C_{D_{0v.t\text{ app}}}$</td>
<td>0.0011</td>
<td>0.0011</td>
<td>0.0011</td>
<td>0.0011</td>
<td>0.0011</td>
</tr>
<tr>
<td>But $C_{D_{0v.t}} = C_{D_{v.t}}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>then $C_{D_{v.t}}$</td>
<td>0.0012</td>
<td>0.0012</td>
<td>0.0012</td>
<td>0.0012</td>
<td>0.0012</td>
</tr>
</tbody>
</table>
\[ C_{D_{p}} = C_{D_{n}} + C_{D_{P}} + C_{n_{int}} + L C_{p_{wm_{x_{p}}}} \]

\[ C_{D_{n}} = C_{D_{n}} \] (\( C_{D_{n}} \) is negligible, \( \approx 0 \))

\[ C_{D_{n}} = C_{D_{n}} \left[ 1 + \frac{60}{(\delta/n_{i})^{3}} + 0.0025 \left( \frac{L_{n}}{2} \right) \right] S_{wet_{n}} / S + C_{D_{n}} \]

<table>
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<th>50 Pax</th>
<th>75 Pax</th>
<th>100 Pax</th>
</tr>
</thead>
<tbody>
<tr>
<td>( l_{n} )</td>
<td>17.5</td>
<td>17.5</td>
<td>17.5</td>
<td>22.9</td>
</tr>
<tr>
<td>( w_{n_{a_{p}} \text{pp}_{a}} )</td>
<td>1.16 \times 10^7</td>
<td>1.16 \times 10^7</td>
<td>1.16 \times 10^7</td>
<td>2.44 \times 10^7</td>
</tr>
<tr>
<td>( C_{p_{a_{p}} \text{pp}_{a}} )</td>
<td>0.0027</td>
<td>0.0027</td>
<td>0.0027</td>
<td>0.0026</td>
</tr>
<tr>
<td>( d_{n} )</td>
<td>3.33</td>
<td>3.33</td>
<td>3.33</td>
<td>4.33</td>
</tr>
<tr>
<td>( S_{wet_{n}} )</td>
<td>53.89</td>
<td>53.89</td>
<td>53.89</td>
<td>92.08</td>
</tr>
</tbody>
</table>

\( C_{D_{n}} = 0 \) because there is no end.

\[ \rightarrow C_{D_{n_{a_{p}} \text{pp}_{a}}} \]

\[ 0.0004 \quad 0.0004 \quad 0.0004 \quad 0.0003 \quad 0.0003 \]

\[ \rightarrow C_{D_{n_{a_{p}} \text{pp}_{a}}} \]

\[ 0.0008 \quad 0.0008 \quad 0.0008 \quad 0.0006 \quad 0.0006 \]

\[ C_{D_{p}} = (R_{p_{pp}})(R_{LS})(C_{p_{p}})[1 + L^{1} \left( \frac{S}{L} \right) + 100 \left( \frac{S}{L} \right)^{4}] S_{wet_{p}} / S \]

\[ \Delta F \text{ (pp)} \quad 0.28 \quad 0.28 \quad 0.28 \quad 0.314 \quad 0.314 \quad \text{(rd)} \]

\[ \Delta F \text{ (corr.)} \quad 71.33 \quad 79.00 \quad 96.33 \quad 77.00 \quad 96.33 \quad \text{(rd)} \]

\[ \Delta F \text{ (app)} \quad 7.6 \times 10^{7} \quad 2.4 \times 10^{7} \quad 1.0 \times 10^{9} \quad 8.4 \times 10^{7} \quad 1.0 \times 10^{9} \]

\[ R_{p_{pp}} \quad 0.930 \quad 0.930 \quad 0.928 \quad 0.930 \quad 0.928 \]

\[ R_{LS_{app}} \quad 1.07 \quad 1.07 \quad 1.07 \quad 1.07 \quad 1.07 \]

\[ \Delta F \text{ (app)} \quad 10.83 \quad 10.83 \quad 10.83 \quad 11.67 \quad 11.67 \]

\[ \Delta F \text{ (app)} \quad 1.2 \times 10^{7} \quad 1.2 \times 10^{7} \quad 1.2 \times 10^{7} \quad 1.24 \times 10^{7} \quad 1.24 \times 10^{7} \]
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<th>( C_{D_{p_{app}}}. )</th>
<th>( C_{D_{p_{aux}}}. )</th>
<th>( C_{D_{p_{tot}}} )</th>
<th>( C_{D_{p_{aux}}} )</th>
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<td>( L' = 1.2 )</td>
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<td>448</td>
<td>448</td>
<td>663</td>
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<tr>
<td>( \frac{b}{c} = .12 )</td>
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<td>592</td>
<td>1182</td>
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<tr>
<td>( \Delta (S_{aux}) )</td>
<td>448</td>
<td>448</td>
<td>448</td>
<td>663</td>
</tr>
<tr>
<td>( S )</td>
<td>592</td>
<td>592</td>
<td>592</td>
<td>1182</td>
</tr>
</tbody>
</table>

\[
C_{D_{p_{aux}}} = 2 \left[ \left( \frac{C_{L_{p}}}{} \right)^2 / \pi \right] \frac{S_{p}}{S}
\]

\[
C_{L_{p}} = C_{L_{\alpha p}} \alpha_{p}
\]

\[
C_{L_{p}} = 1.5320 \quad 1.5320 \quad 1.5320 \quad 1.9622 \quad 1.9622
\]

\[
\alpha_{p} = \alpha (1 - \frac{d \theta}{d \alpha}) \quad \alpha = 1.0
\]

\[
\alpha_{p} = 0.0096 \quad 0.0201 \quad 0.0305 \quad 0.0170 \quad 0.0259
\]

\[
C_{L_{p}} = 0.147 \quad 0.0308 \quad 0.0467 \quad 0.0334 \quad 0.0508
\]

\[
A_{p} = 1.080 \quad 1.080 \quad 1.080 \quad 1.487 \quad 1.487
\]

\[
e_{p} = 5
\]

\[
S_{p} = 112 \quad 112 \quad 112 \quad 165.8 \quad 165.8
\]

\[
C_{D_{L_{p}}} = 0.0001 \quad 0.0002 \quad 0.0005 \quad 0.0001 \quad 0.0003
\]

\[
C_{D_{p}} = C_{D_{p_{aux}}} + C_{D_{L_{p}}}
\]

\[
C_{D_{p}} = 0.0026 \quad 0.0026 \quad 0.0030 \quad 0.0020 \quad 0.0022
\]
\[ CD_{n,\text{int}} \] is negligible because of the large distance between the nacelle and the fuselage. Actually, that interference has been accounted for in the \( CD \) calculations.

\[ \Delta CD_{\text{wmp prop}} = 2 \left[ 33 \left( \frac{1}{4} \right) \frac{SHP_{\text{rated}} \left( \frac{1}{U_1} \right)}{\text{unit}} \right] \quad \text{(2 engines)} \]

<table>
<thead>
<tr>
<th></th>
<th>25 Pax</th>
<th>36 Pax</th>
<th>50 Pax</th>
<th>75 Pax</th>
<th>100 Pax</th>
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</thead>
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<tr>
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<td>592</td>
<td>592</td>
<td>1182</td>
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<tr>
<td>( \frac{SHP_{\text{rated}}}{\text{per engine}} )</td>
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<tr>
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<td>11000</td>
<td>11000</td>
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<tr>
<td>( U_1 )</td>
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<td>696.29</td>
<td>696.29</td>
<td>696.29</td>
<td>696.29</td>
</tr>
</tbody>
</table>

\[ \Delta CD_{\text{wmp}} \quad 0.0041 \quad 0.0041 \quad 0.0041 \quad 0.0041 \quad 0.0041 \]

Then,

\[ CD_{\text{np}} \quad 0.0075 \quad 0.0075 \quad 0.0079 \quad 0.0067 \quad 0.0069 \]
the calculations presented here are applied only at low speed (which is at approach M=0).

\[ C_{D_{\text{gear}}} = \left[ C_{D_{\text{now gear}}} + C_{D_{\text{no gear}}} \right] \]

For landing gears with more than one wheel per bogey:

\[ C_{D_{\text{mgear}}} = \frac{D_{\text{gear}}}{S} \quad \text{(main gear)} \]

\[ C_{D_{\text{mg}} = \left( C_{D_{\text{mgear}}} + p \cdot C_L \right) \frac{S_{\text{gear}}}{S} \quad \text{where } p = -0.4 \cdot C_{D_{\text{mgear}}} \]

\[
\begin{align*}
a &= 14 \text{ ft} \\
b &= 1.9 \text{ ft} \\
d &= 1.5 \text{ ft} \\
e &= 4.2 \text{ ft} \\
\end{align*}
\]

Fig. 4.58: 
\[ C_{D_{\text{mgear}}} = 0.8 \Rightarrow p = 0.32 \]

\[ C_L = \frac{W}{\frac{S}{S}} \]

\[ S_{\text{gear}} = b_e \times D_e = 2.85 \text{ ft}^2 \]

<table>
<thead>
<tr>
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<th>(50\text{ Pax})</th>
<th>(75\text{ Pax})</th>
<th>(100\text{ Pax})</th>
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</thead>
<tbody>
<tr>
<td>(W)</td>
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<td>35,954</td>
<td>43,141</td>
<td>71,419</td>
</tr>
<tr>
<td>(S)</td>
<td>592</td>
<td>592</td>
<td>592</td>
<td>1182</td>
</tr>
<tr>
<td>(\alpha_{\text{app}})</td>
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<td>39.4</td>
<td>39.8</td>
<td>40.24</td>
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<tr>
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<td>1.54</td>
<td>1.83</td>
<td>1.50</td>
</tr>
<tr>
<td>Fig. 4.60</td>
<td>(\Delta p_{\text{gear}})</td>
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<td>25</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>25 Pax</td>
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<tr>
<td>------</td>
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<td>$C_{D_{m,ger}}$</td>
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<td>0.0010</td>
<td>0.0030</td>
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<td>0.0456</td>
<td>0.0844</td>
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</tr>
<tr>
<td>$C_{D_{bear}}$</td>
<td>0.0421</td>
<td>0.0466</td>
<td>0.0874</td>
<td>0.0932</td>
</tr>
</tbody>
</table>

Then, consider...
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.
Performance Validation for the Family of Commuter Airplanes

**Take-off Distance Calculations**

<table>
<thead>
<tr>
<th>Ground Distance</th>
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<th>36</th>
<th>50</th>
<th>75</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>W-TO = W-L (lbs)</td>
<td>28506</td>
<td>35954</td>
<td>43141</td>
<td>71419</td>
<td>85044</td>
</tr>
<tr>
<td>Thrust-TO (lbs)</td>
<td>14283</td>
<td>17330</td>
<td>21461</td>
<td>34224</td>
<td>41727</td>
</tr>
<tr>
<td>Friction Coeff.</td>
<td>.025</td>
<td>.025</td>
<td>.025</td>
<td>.025</td>
<td>.025</td>
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<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>T/W - T.O.</td>
<td>.501</td>
<td>.482</td>
<td>.497</td>
<td>.479</td>
<td>.491</td>
</tr>
<tr>
<td>F-s (lbs)</td>
<td>13570</td>
<td>16431</td>
<td>20382</td>
<td>32439</td>
<td>39501</td>
</tr>
</tbody>
</table>

| 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      |
### Landing Distance Calculations

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<th>S-T.O. (ft)</th>
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<th>3465</th>
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<td>1.71</td>
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<td>2.02</td>
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<td>172.9</td>
<td>172.9</td>
<td>172.9</td>
<td>172.9</td>
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<td>V-A (fps)</td>
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<td>1.20</td>
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<td>q-bar-A (psf)</td>
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<td>.247</td>
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<td>D-A (lbs)</td>
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<td>7111</td>
<td>8818</td>
<td>17535</td>
<td>20304</td>
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<td>1916</td>
<td>1875</td>
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| Land. Dist. S-L (ft) | 3365 | 3467 | 3468 | 3337 | 3370 |
### Climb Requirements

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<th>#</th>
<th>FAR Req.</th>
<th>Flap Set</th>
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<th>VxVs</th>
<th>Thrust Set</th>
<th>Wt.</th>
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<td>1.2</td>
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<td>TO</td>
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<td>2</td>
<td>25.121 OEI transition</td>
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<td>1.15</td>
<td>TO</td>
<td>TO</td>
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<td>3</td>
<td>25.121 OEI 2nd segment</td>
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<td>1.2</td>
<td>TO</td>
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<td>25.121 OEI en route</td>
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<td>1.25</td>
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<td>6</td>
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<td>down</td>
<td>1.1&lt;V</td>
<td>TO</td>
<td>L</td>
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### Actual Climb Gradients

#### Case 1 — Initial

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</thead>
<tbody>
<tr>
<td>Weight (lbs)</td>
<td>28506</td>
<td>35954</td>
<td>43141</td>
<td>71419</td>
</tr>
<tr>
<td>Thrust (lbs)</td>
<td>7142</td>
<td>8665</td>
<td>10731</td>
<td>17112</td>
</tr>
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### Actual Climb Gradients for the Commuter Family

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### Performance Verification

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Appendix I

Airport Dimensions

Purpose: This appendix checks taxiway widths to determine what airports the twinbody configurations can operate from.
### Aircraft Characteristics Related to Airport Design

#### TABLE 3-1: Characteristics of Principal Transport Aircraft

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<th>Length (ft)</th>
<th>Wheelbase (ft)</th>
<th>Wheel Track (ft)</th>
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</tbody>
</table>

70,000 to 755,000 lb. Small general aviation aircraft weights range from 2000 to 6000 lb, while commuter and corporate aircraft vary from 15,000 to 74,000 lb. The maximum number of passengers carried by airline aircraft varies from 100 to 800. 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 5000 to 15,000 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.
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 airliners are powered in this manner. The term jet makes reference to those aircraft which are not dependent on propellers for thrust, but which obtain the thrust directly from a jet engine. The easily jet-powered aircraft, particularly the Convair 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 3-2 Characteristics of General Aviation and Short-Haul Passenger Aircraft

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Wing span</th>
<th>Fuselage length</th>
<th>Wheel track</th>
<th>Maximum weight, lb</th>
<th>Maximum number of seats</th>
<th>Minimum engines, length, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bucker 20</td>
<td>22' 0&quot;</td>
<td>20' 0&quot;</td>
<td>12' 0&quot;</td>
<td>2,200</td>
<td>4</td>
<td>1 F, 2.200</td>
</tr>
<tr>
<td>Bucker 25</td>
<td>23' 0&quot;</td>
<td>22' 0&quot;</td>
<td>13' 0&quot;</td>
<td>2,400</td>
<td>6</td>
<td>1 P, 2.500</td>
</tr>
<tr>
<td>Bucker 28</td>
<td>27' 0&quot;</td>
<td>26' 0&quot;</td>
<td>14' 0&quot;</td>
<td>2,700</td>
<td>6</td>
<td>2 P, 2.800</td>
</tr>
<tr>
<td>Bucker 30</td>
<td>27' 0&quot;</td>
<td>26' 0&quot;</td>
<td>14' 0&quot;</td>
<td>2,900</td>
<td>6</td>
<td>3 P, 3.000</td>
</tr>
<tr>
<td>Bucker 35</td>
<td>31' 0&quot;</td>
<td>30' 0&quot;</td>
<td>15' 0&quot;</td>
<td>3,100</td>
<td>8</td>
<td>3 P, 3.300</td>
</tr>
<tr>
<td>Bucker 40</td>
<td>32' 0&quot;</td>
<td>31' 0&quot;</td>
<td>13' 0&quot;</td>
<td>3,800</td>
<td>8</td>
<td>5 P, 3.800</td>
</tr>
<tr>
<td>Bucker 45</td>
<td>34' 0&quot;</td>
<td>33' 0&quot;</td>
<td>15' 0&quot;</td>
<td>4,500</td>
<td>8</td>
<td>6 P, 4.500</td>
</tr>
<tr>
<td>Bucker 50</td>
<td>39' 0&quot;</td>
<td>38' 0&quot;</td>
<td>16' 0&quot;</td>
<td>5,500</td>
<td>12</td>
<td>7 P, 5.500</td>
</tr>
<tr>
<td>Bucker 60</td>
<td>45' 0&quot;</td>
<td>44' 0&quot;</td>
<td>17' 0&quot;</td>
<td>6,700</td>
<td>14</td>
<td>8 P, 6.700</td>
</tr>
<tr>
<td>Bucker 70</td>
<td>51' 0&quot;</td>
<td>50' 0&quot;</td>
<td>18' 0&quot;</td>
<td>8,000</td>
<td>16</td>
<td>9 P, 8.000</td>
</tr>
<tr>
<td>Bucker 80</td>
<td>55' 0&quot;</td>
<td>54' 0&quot;</td>
<td>19' 0&quot;</td>
<td>9,000</td>
<td>18</td>
<td>10 P, 9.000</td>
</tr>
<tr>
<td>Bucker 90</td>
<td>60' 0&quot;</td>
<td>59' 0&quot;</td>
<td>20' 0&quot;</td>
<td>10,000</td>
<td>20</td>
<td>11 P, 10.000</td>
</tr>
<tr>
<td>Bucker 100</td>
<td>65' 0&quot;</td>
<td>64' 0&quot;</td>
<td>21' 0&quot;</td>
<td>12,000</td>
<td>22</td>
<td>12 P, 12.000</td>
</tr>
<tr>
<td>Bucker 120</td>
<td>70' 0&quot;</td>
<td>69' 0&quot;</td>
<td>22' 0&quot;</td>
<td>15,000</td>
<td>25</td>
<td>15 P, 15.000</td>
</tr>
<tr>
<td>Bucker 140</td>
<td>75' 0&quot;</td>
<td>74' 0&quot;</td>
<td>23' 0&quot;</td>
<td>20,000</td>
<td>30</td>
<td>20 P, 20.000</td>
</tr>
<tr>
<td>Bucker 160</td>
<td>80' 0&quot;</td>
<td>79' 0&quot;</td>
<td>24' 0&quot;</td>
<td>25,000</td>
<td>35</td>
<td>25 P, 25.000</td>
</tr>
</tbody>
</table>

### Table 3-3 Main Landing Gear Dimensions for Typical Transport Aircraft

<table>
<thead>
<tr>
<th>Main landing gear configuration</th>
<th>Aircraft</th>
<th>Dimensions, in</th>
<th>Typical inflation pressures, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC-6-60</td>
<td>58.1</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>B-727</td>
<td>54.3</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>B-728</td>
<td>54.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>DC-8-61</td>
<td>26.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>B-729</td>
<td>54.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>DC-8-62</td>
<td>26.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>B-730</td>
<td>54.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>DC-8-63</td>
<td>26.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>B-731</td>
<td>54.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>DC-10-10</td>
<td>54.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>B-732</td>
<td>54.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>DC-10-20</td>
<td>54.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>B-733</td>
<td>54.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>DC-10-30</td>
<td>54.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>B-734</td>
<td>54.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>DC-10-40</td>
<td>54.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>B-735</td>
<td>54.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>DC-10-50</td>
<td>54.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>B-736</td>
<td>54.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>DC-10-60</td>
<td>54.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>B-737</td>
<td>54.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>DC-10-70</td>
<td>54.0</td>
<td>162</td>
<td></td>
</tr>
<tr>
<td>B-738</td>
<td>54.0</td>
<td>162</td>
<td></td>
</tr>
</tbody>
</table>

* Including pilot and crew.

** Source: Manufacturers' data; Jane's All the World's Aircraft 1971.
Geometric Design of the Landing Area

TABLE 9-3 FAA Aircraft Approach Category Classification

<table>
<thead>
<tr>
<th>Approach category</th>
<th>Approach speed, kn</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Less than 91</td>
</tr>
<tr>
<td>B</td>
<td>91-120</td>
</tr>
<tr>
<td>C</td>
<td>121-140</td>
</tr>
<tr>
<td>D</td>
<td>141-165</td>
</tr>
<tr>
<td>E</td>
<td>166 or greater</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Airplane design group</th>
<th>Wingspan, ft</th>
<th>Typical aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Less than 49</td>
<td>Learjet 24, Rockwell Sabre 75A</td>
</tr>
<tr>
<td>II</td>
<td>49 but less than 79</td>
<td>Gulfstream II, Rockwell Sabre 50</td>
</tr>
<tr>
<td>III</td>
<td>79 but less than 118</td>
<td>B-727, B-737, BAC-111, B-757, B-767, Concorde, L-1011, DC-9</td>
</tr>
<tr>
<td>IV</td>
<td>118 but less than 171</td>
<td>A-300, A-310, B-707, DC-8</td>
</tr>
<tr>
<td>V</td>
<td>171 but less than 197</td>
<td>B-747</td>
</tr>
<tr>
<td>VI</td>
<td>197 but less than 262</td>
<td>Future</td>
</tr>
</tbody>
</table>

SOURCE: Federal Aviation Administration [129, 23].
Table 7.5 Recommended Dimensional Standards for Airline Airports—Taxiways

<table>
<thead>
<tr>
<th>Design Item</th>
<th>Symbol</th>
<th>Dimensional Criteria (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Group I</td>
</tr>
<tr>
<td>1. Taxiway structural pavement width on tangents</td>
<td>(W_T)</td>
<td>50</td>
</tr>
<tr>
<td>2. Taxiway structural pavement width on curves</td>
<td>(W_C)</td>
<td>65</td>
</tr>
<tr>
<td>3. Taxiway shoulder width</td>
<td>—</td>
<td>20</td>
</tr>
<tr>
<td>4. Safety area width</td>
<td>—</td>
<td>110</td>
</tr>
<tr>
<td>5. Taxiway and apron taxiway obstacle-free area width</td>
<td>—</td>
<td>210</td>
</tr>
<tr>
<td>6. Terminal taxilane obstacle-free area width</td>
<td>—</td>
<td>160</td>
</tr>
<tr>
<td>7. Separation distance from taxiway (C_L) to taxiway (C_L)</td>
<td>(S_T)</td>
<td>200</td>
</tr>
<tr>
<td>8. Separation distance from taxiway (C_L) to runway (C_L)</td>
<td>(S_T)</td>
<td>400</td>
</tr>
<tr>
<td>9. Radius of taxiway (C_L) curves</td>
<td>(R)</td>
<td>100</td>
</tr>
</tbody>
</table>

Longitudinal Grade Details

7.6 summarize the ICAO dimensional as described in Section 2.3 defined in Table 7.5. To use this table, enter the wingspan, undercarriage width, and airplane design group. Select the appropriate dimension.

Transverse Grades

As shown in the table, transverse runways are sloped away from the runway centerline, with drainage requirements to remove water on the surface. However, runways that serve runways that serve ICAO runways are recommended to have a maximum grade of 5.0% for shoulders.

Beyond the runway end, the removal of surfacematerial may involve earth. The construction of a smooth, complete.

7.7 LONGITUDINAL

From the start of the runway, the level of the surface is


210
### Table 7.4 FAA Minimum Dimensional Standards for General Aviation Airports

<table>
<thead>
<tr>
<th>Design Item</th>
<th>Basic Utility Stage I</th>
<th>Basic Utility Stage II</th>
<th>General Utility</th>
<th>Precision Runway for Basic or General Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runway safety area width (ft)</td>
<td>100</td>
<td>120</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Runway width (ft)</td>
<td>50</td>
<td>60</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>Taxiway width (ft)</td>
<td>20</td>
<td>30</td>
<td>40 (40-60)</td>
<td>40-60 (40-60)</td>
</tr>
<tr>
<td>Runway centerline to Taxiway centerline (ft)</td>
<td>150</td>
<td>150</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Taxiway centerline to Airplane parking area (ft)</td>
<td>225</td>
<td>225</td>
<td>375</td>
<td>375</td>
</tr>
<tr>
<td>Building restriction line (ft)</td>
<td>200</td>
<td>200</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Taxiway centerline to Airplane parking area (ft)</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>Fixed or movable obstacle (ft)</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Parallel taxiway (ft)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>150</td>
</tr>
<tr>
<td>Building restriction line (ft)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>


### Table 7.7 Runway Longitudinal Grade Design Criteria for Civilian Airports

| Source/Code | 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, ft
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>FAA</td>
<td>1.5</td>
<td>0.5</td>
<td>1.0</td>
<td>1.5</td>
<td>1000 (A + B)</td>
<td>1000</td>
</tr>
<tr>
<td>Basic and general transport airports</td>
<td>2.0</td>
<td>-</td>
<td>-</td>
<td>2.0</td>
<td>250 (A + B)</td>
<td>300</td>
</tr>
<tr>
<td>Utility airports</td>
<td>2.0</td>
<td>-</td>
<td>-</td>
<td>2.0</td>
<td>250 (A + B)</td>
<td>300</td>
</tr>
<tr>
<td>ICAO Code letter A</td>
<td>1.25</td>
<td>0.8</td>
<td>1.0</td>
<td>1.5</td>
<td>1000 (A + B)</td>
<td>1000</td>
</tr>
<tr>
<td>Code letter B</td>
<td>1.25</td>
<td>0.8</td>
<td>1.0</td>
<td>1.5</td>
<td>1000 (A + B)</td>
<td>1000</td>
</tr>
<tr>
<td>Code letter C</td>
<td>1.5</td>
<td>-</td>
<td>1.0</td>
<td>1.5</td>
<td>500 (A + B)</td>
<td>500</td>
</tr>
<tr>
<td>Code letter D</td>
<td>2.0</td>
<td>-</td>
<td>2.0</td>
<td>2.0</td>
<td>165 (A + B)</td>
<td>250</td>
</tr>
<tr>
<td>Code letter E</td>
<td>2.0</td>
<td>-</td>
<td>2.0</td>
<td>2.0</td>
<td>165 (A + B)</td>
<td>250</td>
</tr>
</tbody>
</table>

Sources: Utility Airports, FAA Advisory Circular AC 150/5300-48, June 24, 1975. Airport Design Standards—General Aviation Airports—Basic and General Transport, FAA Advisory Circular AC 150/5300-46 including CHC 1, April 13, 1972. Runway grade changes shall also conform to sight distance criteria described in section 7.7. No vertical curve is required when grade change is less than 0.4%. 

---

Table 7.4 and Table 7.7 provide dimensional and grade design criteria for general aviation and civilian airports, respectively. These tables are essential for planning and designing airports to ensure safety and functionality.
Table 7.3 ICAO Minimum Dimensional Recommended Practices

<table>
<thead>
<tr>
<th>Design Item</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width of cleared and graded area</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instrument runway (ft)</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Noninstrument runway (ft)</td>
<td>500</td>
<td>500</td>
<td>400</td>
<td>260</td>
<td>200</td>
</tr>
<tr>
<td>Runway width (ft)</td>
<td>150</td>
<td>150</td>
<td>100</td>
<td>75</td>
<td>60</td>
</tr>
<tr>
<td>Taxiway width (ft)</td>
<td>75</td>
<td>75</td>
<td>50</td>
<td>33</td>
<td>25</td>
</tr>
<tr>
<td>Taxiway edge to:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Edge of instrument runway (ft)</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Edge of other runway (ft)</td>
<td>250</td>
<td>240</td>
<td>240</td>
<td>120</td>
<td>95</td>
</tr>
<tr>
<td>Edge of another taxiway (ft)</td>
<td>205</td>
<td>170</td>
<td>140</td>
<td>90</td>
<td>75</td>
</tr>
<tr>
<td>A fixed obstruction (ft)</td>
<td>125</td>
<td>100</td>
<td>85</td>
<td>60</td>
<td>53</td>
</tr>
</tbody>
</table>


Table 7.4 FAA Recommended Dimensional Standards for Airline Airports—Runways

<table>
<thead>
<tr>
<th>Design Item</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runway safety area width (ft)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>150</td>
</tr>
<tr>
<td>Runway width (ft)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Runway centerline to:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building restriction line (ft)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>750</td>
</tr>
<tr>
<td>Airplane parking area</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Property line</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Determined by imaginary surfaces
(See FAR Part 77 and Ref. 6)

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 CHC 1, June 14, 1976.

*A 200 ft runway width is recommended where airplanes in Design Group III (see Table 7.5) are planned to be accommodated.
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

RUNWAYS

The runway system at an airport consists of the structural pavement, the
shoilders, 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 equip-
ment.

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 210 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 400 ft for precision
instrument operations with small aircraft. It also requires 1000 ft for large
aircraft in all design groups. The runway safety area 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 grades, 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