PRESENTATION OF CLASS I DESIGNS
FOR A FAMILY OF COMMUTER AIRPLANES

Prepared for: NASA Grant NGT-80001
Prepared by: University of Kansas
AE 790 Design Team
November 1986

Team Leader: Tom Creighton
Team Members: George Dragush
Louis Hendrich
Doug Hensley
Louise Morgan
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John Remen
Terry Robinson
Mark Russell
Jerry Swift

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<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>
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<td>c_c</td>
<td>Wing mean geometric chord</td>
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<tr>
<td>c_f</td>
<td>Flap chord</td>
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<tr>
<td>c_f</td>
<td>Equivalent skin friction coefficient</td>
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<tr>
<td>c_j</td>
<td>Specific fuel consumption</td>
<td>lbs/lbs/hr</td>
</tr>
<tr>
<td>C_d</td>
<td>Drag coefficient</td>
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<td>Section lift coefficient</td>
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<td>c_l a</td>
<td>Section lift curve slope</td>
<td>1/rad</td>
</tr>
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<td>c_l a_f</td>
<td>Section lift curve slope with flaps down</td>
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<tr>
<td>c_l</td>
<td>Lift Coefficient</td>
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</tr>
<tr>
<td>c_m</td>
<td>Pitching moment coefficient</td>
<td>ft</td>
</tr>
<tr>
<td>D</td>
<td>Drag</td>
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<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>
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<td>Fuselage diameter</td>
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</tr>
<tr>
<td>e</td>
<td>Oswald's efficiency factor</td>
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</tr>
<tr>
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<td>Endurance</td>
<td>hours</td>
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<td>f_ar</td>
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<tr>
<td>g</td>
<td>Acceleration of gravity</td>
<td>ft</td>
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<tr>
<td>h</td>
<td>Altitude</td>
<td>ft</td>
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<tr>
<td>I_w</td>
<td>Wing incidence angle</td>
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<td>k_{A}</td>
<td>Sweep angle correction factor</td>
<td>ft</td>
</tr>
<tr>
<td>k_f</td>
<td>Correction factor for split flaps</td>
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</tr>
<tr>
<td>L</td>
<td>Lift</td>
<td>lbs</td>
</tr>
<tr>
<td>L/D</td>
<td>Lift-to-drag ratio</td>
<td>ft</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>
<tr>
<td>Symbol</td>
<td>Definition</td>
<td>Unit</td>
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<td>--------</td>
<td>-----------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>( l_n )</td>
<td>Dist. c.g. to nose gear</td>
<td>ft</td>
</tr>
<tr>
<td>( M )</td>
<td>Mach number</td>
<td>-----</td>
</tr>
<tr>
<td>( \text{nm} )</td>
<td>Load factor</td>
<td>-----</td>
</tr>
<tr>
<td>( \text{nm} )</td>
<td>Nautical mile (6,076 ft)</td>
<td>nm</td>
</tr>
<tr>
<td>( N_p )</td>
<td>Number of propeller blades</td>
<td>-----</td>
</tr>
<tr>
<td>( N_s )</td>
<td>Number of struts</td>
<td>-----</td>
</tr>
<tr>
<td>( N_e )</td>
<td>Number of engines</td>
<td>-----</td>
</tr>
<tr>
<td>( P_b )</td>
<td>Power, horse-power</td>
<td>hp/ft²</td>
</tr>
<tr>
<td>( q )</td>
<td>Blade power loading</td>
<td>psf</td>
</tr>
<tr>
<td>( R_n )</td>
<td>Reynold's number</td>
<td>-----</td>
</tr>
<tr>
<td>( RC )</td>
<td>Rate of climb</td>
<td>fpm or fps</td>
</tr>
<tr>
<td>( S )</td>
<td>Distance</td>
<td>ft</td>
</tr>
<tr>
<td>( SHP )</td>
<td>Wing area</td>
<td>ft²</td>
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<tr>
<td>( S_{\text{wet}} )</td>
<td>Shaft horsepower</td>
<td>hp</td>
</tr>
<tr>
<td>( S_{\text{wet}} )</td>
<td>Wetted area</td>
<td>ft²</td>
</tr>
<tr>
<td>( t )</td>
<td>Time</td>
<td>sec, min, hr</td>
</tr>
<tr>
<td>( t/c )</td>
<td>Thickness ratio</td>
<td>-----</td>
</tr>
<tr>
<td>( T )</td>
<td>Thrust</td>
<td>lbs</td>
</tr>
<tr>
<td>( V )</td>
<td>True airspeed</td>
<td>mph, fps, kts</td>
</tr>
<tr>
<td>( V )</td>
<td>Volume coefficient</td>
<td>-----</td>
</tr>
<tr>
<td>( W )</td>
<td>Weight</td>
<td>lbs</td>
</tr>
<tr>
<td>( X_{\text{ac}} )</td>
<td>Distance from l.e. c to aerodynamic center</td>
<td>-----</td>
</tr>
<tr>
<td>( X, Y, Z )</td>
<td>Distance from reference to a component c.g.</td>
<td>ft, in</td>
</tr>
<tr>
<td>( X_{\text{v}}, X_{\text{h}}, X_{c} )</td>
<td>Distance from c.g. to a.c. of a surface</td>
<td>ft, in</td>
</tr>
<tr>
<td>( Y_t )</td>
<td>Engine-out moment arm</td>
<td>ft</td>
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**Greek Symbols**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha )</td>
<td>Angle of attack</td>
<td>deg, rad</td>
</tr>
<tr>
<td>( \beta )</td>
<td>Sideslip angle</td>
<td>deg, rad</td>
</tr>
<tr>
<td>( \delta )</td>
<td>Control surface deflection</td>
<td>deg, rad</td>
</tr>
<tr>
<td>( \lambda )</td>
<td>Taper ratio</td>
<td>-----</td>
</tr>
<tr>
<td>( \lambda )</td>
<td>Sweep angle</td>
<td>deg, rad</td>
</tr>
<tr>
<td>( \pi )</td>
<td>3.142</td>
<td>-----</td>
</tr>
<tr>
<td>( \Gamma )</td>
<td>Dihedral angle</td>
<td>deg, rad</td>
</tr>
<tr>
<td>( \rho )</td>
<td>Air density</td>
<td>slugs/ft</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>Air density ratio</td>
<td>-----</td>
</tr>
<tr>
<td>( \theta_{\text{fc}} )</td>
<td>Fuselage cone angle</td>
<td>deg, rad</td>
</tr>
<tr>
<td>( \theta )</td>
<td>Lateral ground clearance angle</td>
<td>deg, rad</td>
</tr>
<tr>
<td>( \theta )</td>
<td>Longitudinal ground clearance angle</td>
<td>deg, rad</td>
</tr>
<tr>
<td>( \theta_{\text{lof}} )</td>
<td>Lift-off angle</td>
<td>deg, rad</td>
</tr>
<tr>
<td>Symbol</td>
<td>Concept</td>
<td>Units</td>
</tr>
<tr>
<td>--------</td>
<td>---------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>$c$</td>
<td>Downwash angle</td>
<td>-----</td>
</tr>
<tr>
<td>$c_t$</td>
<td>twist angle</td>
<td>deg, rad</td>
</tr>
<tr>
<td>$n$</td>
<td>spanwise station, fraction of the span</td>
<td>-----</td>
</tr>
<tr>
<td>$w$</td>
<td>lateral tip-over angle</td>
<td>deg, rad</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>flight path angle</td>
<td>deg, rad</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>bypass ratio</td>
<td>-----</td>
</tr>
</tbody>
</table>

**Subscripts**

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

Acronyms

AEO  All engines operating
APU  Auxiliary power unit
B.L.  Buttock line
c.g.  Center of gravity
F.S.  Fuselage station, Front spar
OEI  One engine inoperative
OWE  Operating weight empty
PAX  Passengers
p.d.  Preliminary design
R.S.  Rear Spar
sls  Sea level standard
TBP  Turboprop
W.L.  Waterline
1.0 INTRODUCTION

This report is completed in partial fulfillment of NASA-USRA Grant NGT-8001 requirements. The purpose of this report is to present the class I configuration designs of a family of commuter airplanes.

The proposed commuters range from 25 to 100 passengers. It was decided that all the airplanes in the family should have:

1) 2 aft fuselage mounted engines
2) Low wing
3) T-tail type empennage
4) Tricycle type landing gear

The family concept is introduced in this report in an effort 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. Table 1.1 lists these common features. 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.

Chapter 2. discusses the commonality objectives to be designed into the commuter family. Chapter 3. discusses the seven class I configuration designs. Chapter 4. compares the design data to existing airplanes. The extent of structural, systems, and handling qualities commonality achieved will be reviewed in Chapter 5. Conclusions and recommendations are contained in Chapter 6.
<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 and brakes (Both nose and main gear)</td>
<td></td>
</tr>
<tr>
<td>Common landing gear struts and retraction scheme</td>
<td>Completed</td>
</tr>
<tr>
<td>Common wing torque box</td>
<td>Completed*</td>
</tr>
<tr>
<td>Common empennage torque box</td>
<td>Forthcoming</td>
</tr>
<tr>
<td>Common powerplants</td>
<td>Completed**</td>
</tr>
<tr>
<td>Common cockpit Instrumentation</td>
<td>Completed</td>
</tr>
<tr>
<td>Common flight systems</td>
<td>Forthcoming</td>
</tr>
<tr>
<td>Flight control</td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td></td>
</tr>
<tr>
<td>Pressurization</td>
<td></td>
</tr>
<tr>
<td>De-icing</td>
<td></td>
</tr>
<tr>
<td>NLF airfoil technology</td>
<td>Implemented</td>
</tr>
</tbody>
</table>

*Structural analysis in progress

**Two powerplants were selected. A 6000 shp engine, and a 13500 shp engine for the 75 and 100 passenger models.
2. Commonality Objectives for the Commuter Family

The purpose of this chapter is to state the items (structural, systems, operational) that are or will be common to every airplane in the commuter family. After the Class I configurations are presented, an analysis of the extent in which commonality was integrated will be detailed. This is accomplished in Chapter 5.

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 Fuselage Cross Section

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.

2.2 Flight Deck Layout

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.

2.3 Powerplant Selection

The commuter family utilizes an advanced turbo-prop engine with 10 ft. diameter counter-rotating propellers. From engine sizing requirements discussed in Chapter 3, it was determined that cruise speed and landing fieldlength requirements were critical. These requirements determined the required take-off power for each member of the commuter family.

Two shp models were necessary. A 6000 shp engine powers the 25 to 50 passenger models. A 13,500 shp engine powers the 75 and 100 passenger models. For some of the airplanes, it is necessary to derate the engine horsepower. Table 2.1 presents required take-off power requirements and derated horsepower for the commuter family.

Derating some of the engines will allow for longer service life because engine cores will not have to burn as hot and will be able to last longer. Figure 2.3 presents dimensioned view of the PD436-11 powerplant. The engines used in the commuter family are scaled from this engine.
Figure 2.3 PD436-11 Powerplant
Table 2.1 -- Engine Power Requirements.

<table>
<thead>
<tr>
<th>Passenger Model</th>
<th>Take-Off Power (shp)</th>
<th>Total Engine Power (shp)</th>
<th>Derated Engine Power (shp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 Passenger</td>
<td>8,419</td>
<td>2x6000</td>
<td>2x4500</td>
</tr>
<tr>
<td>36 Passenger</td>
<td>8,970</td>
<td>2x6000</td>
<td>2x4500</td>
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<tr>
<td>50 Passenger</td>
<td>11,000</td>
<td>2x6000</td>
<td>--</td>
</tr>
<tr>
<td>75 Pass. (conv.)</td>
<td>19,640</td>
<td>2x13,500</td>
<td>2x10,000</td>
</tr>
<tr>
<td>100 Pass. (conv.)</td>
<td>26,750</td>
<td>2x13,500</td>
<td>--</td>
</tr>
<tr>
<td>Twin-body 75 Pass.</td>
<td>18,000</td>
<td>2x13,500</td>
<td>2x9,000</td>
</tr>
<tr>
<td>Twin-body 100 Pass.</td>
<td>22,000</td>
<td>2x13,500</td>
<td>2x11,000</td>
</tr>
</tbody>
</table>

2.4 Wing and Airfoil Design

A natural laminar flow airfoil similiar to the HSNLF(1)-0213 is used on all members of the commuter family. Appendix C presents the airfoil cross section and design data. Table 2.2 contains Reynolds numbers for the wings. Transition Reynolds numbers directly related to the amount of laminar flow obtained on the airfoil. These Reynolds numbers range from approximately 11 to 30 million. As the Reynolds number increases over the wing, less chordwise laminar flow is realized.

To minimize induced drag an aspect ratio 12 cantilever wing was designed for all airplanes in the commuter family. The high aspect ratio translates into a relatively heavy wing. Appendix D contains a wing weight trade study. Table 2.3 contains the wing planform geometry for all of the commuter family.

2.5 Landing Gear

All landing gear, nose and main, have the same 30" x 9" tire. The main gear wheel base and retraction scheme is desired to be the same. This allows for similar strut sizing for the airplanes. Appendix D contains the main gear retraction scheme for the commuter family. A landing gear tire size study is also included in Appendix D. Table 2.4 provides the number and size of the tires on each gear strut.
### Table 2.2—Wing Reynolds Numbers for the Commuter Family.

<table>
<thead>
<tr>
<th>Passenger Model</th>
<th>$R_{N_{\text{root}}} \times 10^6$</th>
<th>$R_{N_{\text{tip}}} \times 10^6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 Pax</td>
<td>16.9</td>
<td>6.8</td>
</tr>
<tr>
<td>36 Pax</td>
<td>17.4</td>
<td>7.0</td>
</tr>
<tr>
<td>50 Pax</td>
<td>19.9</td>
<td>8.0</td>
</tr>
<tr>
<td>75 Pax (conv.)</td>
<td>28.2</td>
<td>11.3</td>
</tr>
<tr>
<td>100 Pax (conv.)</td>
<td>32.9</td>
<td>13.2</td>
</tr>
<tr>
<td>Twin-body 75 Pax</td>
<td>17.4</td>
<td>7.0</td>
</tr>
<tr>
<td>Twin-body 100 Pax</td>
<td>19.9</td>
<td>8.0</td>
</tr>
</tbody>
</table>

### Table 2.3—Wing Geometry of the Commuter Family.

<table>
<thead>
<tr>
<th>Passenger Model</th>
<th>25 Pax</th>
<th>36 Pax</th>
<th>50 Pax</th>
<th>75 Pax</th>
<th>100 Pax</th>
<th>75 Pax</th>
<th>100 Pax</th>
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<tbody>
<tr>
<td>Model</td>
<td>Pax</td>
<td>Pax</td>
<td>Pax</td>
<td>Pax</td>
<td>Pax (conv.)</td>
<td>Pax</td>
<td>Pax (conv.)</td>
</tr>
<tr>
<td><strong>Parameters</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area, $S ,(\text{ft}^2)$</td>
<td>421</td>
<td>449</td>
<td>591</td>
<td>1178</td>
<td>1604</td>
<td>722</td>
<td>923</td>
</tr>
<tr>
<td>Span, $b ,(\text{ft})$</td>
<td>71.1</td>
<td>73.4</td>
<td>84.3</td>
<td>119</td>
<td>139</td>
<td>105</td>
<td>118</td>
</tr>
<tr>
<td>Aspect ratio, $A$</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
<td>15.1</td>
<td>15.1</td>
</tr>
<tr>
<td>MGC, $\bar{c} ,(\text{ft})$</td>
<td>6.28</td>
<td>6.50</td>
<td>7.46</td>
<td>10.5</td>
<td>11.6</td>
<td>7.50</td>
<td>8.33</td>
</tr>
<tr>
<td>Taper ratio,</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Leading edge sweep, (deg)</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Dihedral, (deg)</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>
2.6 Wing Torque Box

Figure 2.4 presents the 25, 36, and 50 passenger wing planforms with the torque boxes included. These wing planforms are also utilized on the twin body concepts presented in Chapter 3. A common wing carry thru structure is possible if these three planforms are used throughout the family.

Figure 2.5 presents the wing cross sections. The torque box structure is common to all the wing sections. The L.E. and T.E. sections are faired in to retain as much of the NLF airfoil characteristics as possible. Appendix G contains the design work computed for this proposal.

2.7 Tailcone Arrangements

All airplanes in the family have the same fuselage tailcone on all the airplanes. It is desired to keep the vertical tail root spar locations identical positions on all tailcones. When Class II weight and balance work is concluded, a common empennage arrangement will be proposed. Table 2.5 contains empennage geometric data for the commuter family.

2.8 Systems Commonality

Common system design will be attempted for the following systems:

1. Fuel system.
2. Flight controls.
3. Hydraulics.
4. Pressurization.
5. De-icing.

2.8.1 Fuel System

All airplanes in the commuter family carry fuel in the wing. Since a common wing torque box arrangement is proposed, some of the integral fuel tanks can possibly be the same on all airplanes. However, the varying wing spans and required fuel volumes will not allow for complete system commonality. Similar vents and access panels will be incorporated into all members of the family. Fuel flow rates will determine if similar fuel pumps can be used on all family members.

2.8.2 Flight Control System

A separate surface stability augmentation system is proposed to achieve identical handling qualities throughout
Figure 2.5 Wing Cross Sections
Table 2.4--Landing Gear Tire Sizes.

<table>
<thead>
<tr>
<th>Passenger Model</th>
<th>Nose gear</th>
<th>Main gear (per strut)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 Pax</td>
<td>2 x 30&quot; x 9&quot;</td>
<td>2 x 30&quot; x 9&quot;</td>
</tr>
<tr>
<td>36 Pax</td>
<td>2 x 30&quot; x 9&quot;</td>
<td>2 x 30&quot; x 9&quot;</td>
</tr>
<tr>
<td>50 Pax</td>
<td>2 x 30&quot; x 9&quot;</td>
<td>2 x 30&quot; x 9&quot;</td>
</tr>
<tr>
<td>Conv. 75 Pax</td>
<td>2 x 30&quot; x 9&quot;</td>
<td>2 x 30&quot; x 9&quot;</td>
</tr>
<tr>
<td>Conv. 100 Pax</td>
<td>2 x 30&quot; x 9&quot;</td>
<td>4 x 30&quot; x 9&quot;</td>
</tr>
<tr>
<td>Twin 75 Pax</td>
<td>2 x 30&quot; x 9&quot;</td>
<td>2 x 30&quot; x 9&quot;</td>
</tr>
<tr>
<td>Twin 100 Pax</td>
<td>2 x 30&quot; x 9&quot;</td>
<td>2 x 30&quot; x 9&quot;</td>
</tr>
</tbody>
</table>

Table 2.5--Empennage Geometry for the Commuter Family.

<table>
<thead>
<tr>
<th>Passenger Model</th>
<th>25 Pax</th>
<th>36 Pax</th>
<th>50 Pax</th>
<th>75 Pax</th>
<th>100 Pax</th>
<th>75 Pax</th>
<th>100 Pax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
<td>conv.</td>
<td>conv.</td>
<td>twin</td>
<td>twin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal Tail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area, $S_H$ ($ft^2$)</td>
<td>69</td>
<td>69</td>
<td>102</td>
<td>134</td>
<td>155</td>
<td>102</td>
<td>102</td>
</tr>
<tr>
<td>Span, $b_H$ (ft)</td>
<td>16.6</td>
<td>16.6</td>
<td>22.6</td>
<td>26.7</td>
<td>28.7</td>
<td>22.6</td>
<td>22.6</td>
</tr>
<tr>
<td>MGC, $C_H$ (ft)</td>
<td>4.20</td>
<td>4.20</td>
<td>4.68</td>
<td>5.42</td>
<td>5.40</td>
<td>4.68</td>
<td>4.68</td>
</tr>
<tr>
<td>Aspect ratio, $A$</td>
<td>4.0</td>
<td>4.0</td>
<td>5.0</td>
<td>5.3</td>
<td>5.3</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Taper ratio, $\lambda$</td>
<td>0.7</td>
<td>0.7</td>
<td>0.5</td>
<td>0.35</td>
<td>0.35</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>L.E. sweep, (deg)</td>
<td>20</td>
<td>20</td>
<td>25</td>
<td>22</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Vertical tail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area, $S_V$ ($ft^2$)</td>
<td>170</td>
<td>130</td>
<td>170</td>
<td>363</td>
<td>303</td>
<td>130</td>
<td>140</td>
</tr>
<tr>
<td>Span, $b_V$ (ft)</td>
<td>14.0</td>
<td>12.0</td>
<td>15.4</td>
<td>22.5</td>
<td>20.6</td>
<td>12.0</td>
<td>15.4</td>
</tr>
<tr>
<td>MGC, $C_V$ (ft)</td>
<td>13.3</td>
<td>11.9</td>
<td>11.4</td>
<td>16.4</td>
<td>15.0</td>
<td>11.9</td>
<td>9.40</td>
</tr>
<tr>
<td>Aspect ratio, $A$</td>
<td>1.15</td>
<td>1.10</td>
<td>1.40</td>
<td>1.40</td>
<td>1.40</td>
<td>1.10</td>
<td>1.70</td>
</tr>
<tr>
<td>Taper ratio, $\lambda$</td>
<td>0.3</td>
<td>0.3</td>
<td>0.5</td>
<td>0.6</td>
<td>0.6</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>L.E. sweep, (deg)</td>
<td>54</td>
<td>58</td>
<td>40</td>
<td>42</td>
<td>45</td>
<td>58</td>
<td>40</td>
</tr>
</tbody>
</table>
the passenger range. This system will make use of electrohydrostatic actuation. A particular actuator has not yet been decided upon. A control system design has not yet been completed. Figure 2.6 shows a proposed separate surface stability augmentation system that could be incorporated into the commuters.

2.8.3 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.

2.8.4 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.

2.8.5 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. The L.E. volume of the wings will be checked to see if one size system can be implemented.
3. PRESENTATION OF CLASS I DESIGNS

The purpose of this chapter is to document seven class I configurations for the Advanced Technology Commuter Family. The reason for developing these baseline designs is to have a series of reasonably firm configurations on which to perform realistic studies of the feasibility of achieving the commonality goals stated in Table 1.1. The baseline designs evolved from a set of mission specifications listed in Table 3.1.

Sections 3.1 through 3.7 address the class I design evolution of these baseline designs.

Section 3.1 presents the 25 passenger model, the smallest capacity airplane in the family. The subject of section 3.2 is the 36 passenger derivative. The 36 passenger configuration was used to develop a 75 passenger twin fuselage configuration. This 75 passenger configuration is the subject of section 3.3. Section 3.4 presents the 50 passenger derivative. Section 3.5 presents a 100 passenger twin fuselage design. This twin-fuselage was developed from the 50 passenger model. Section 3.6 and 3.7 presents 75 and 100 passenger derivatives that are of conventional configuration. It was found that implementation of many commonality objectives were not possible with these large conventional configurations. A commonality analysis is the subject of chapter 5.

### TABLE 3.1 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>
</tr>
</thead>
<tbody>
<tr>
<td>Payload (lbs)</td>
<td>5125</td>
<td>7380</td>
<td>10250</td>
<td>15375</td>
<td>20500</td>
</tr>
<tr>
<td>Crew (lbs)</td>
<td>410</td>
<td>615</td>
<td>615</td>
<td>820</td>
<td>820</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</td>
<td>Cruise at 30,000 ft.</td>
<td>All Cruise at Mach .70</td>
<td>All</td>
<td>All Field Lengths are 3,500 ft</td>
</tr>
<tr>
<td>Cruise Speed</td>
<td>All</td>
<td>Cruise at Mach .70</td>
<td>All Cruise at Mach .70</td>
<td>All</td>
<td>All Field Lengths are 3,500 ft</td>
</tr>
<tr>
<td>Climb</td>
<td>All</td>
<td>Climb-out at 3000 fpm</td>
<td>All Climb-out at 3000 fpm</td>
<td>All</td>
<td>All Field Lengths are 3,500 ft</td>
</tr>
<tr>
<td>TOFL, LFL</td>
<td>All</td>
<td>Field Lengths are 3,500 ft</td>
<td>All Field Lengths are 3,500 ft</td>
<td>All</td>
<td>All Field Lengths are 3,500 ft</td>
</tr>
<tr>
<td>Powerplants (shp)</td>
<td>6000</td>
<td>6000</td>
<td>6000</td>
<td>13500</td>
<td>13500</td>
</tr>
<tr>
<td>Derated (shp)</td>
<td>4500</td>
<td>4500</td>
<td>4500</td>
<td>6000</td>
<td>6000</td>
</tr>
<tr>
<td>Pressurization</td>
<td>All</td>
<td>Pressurized 5000 ft at 30000 ft</td>
<td>All Pressurized 5000 ft at 30000 ft</td>
<td>All</td>
<td>All Pressurized 5000 ft at 30000 ft</td>
</tr>
<tr>
<td>Certification</td>
<td>All</td>
<td>All</td>
<td>All</td>
<td>All</td>
<td>All</td>
</tr>
</tbody>
</table>
3.1 PRELIMINARY DESIGN OF THE 25 PASSENGER
BASELINE CONFIGURATION

Figure 3.1.1 contains the class I 3-view for the 25
passenger commuter. Table 3.1.1 contains the geometry of the
configurations.

3.1.1 INITIAL WEIGHT AND PERFORMANCE SIZING FOR THE 25
PASSENGER BASELINE CONFIGURATION

3.1.1.1 INITIAL WEIGHT SIZING

Initial weight sizing was conducted using a method in
Reference 1. The following assumptions were made for the
airplane:

1) \((L/D)_{cr} = 16\)
2) \(C_p = 0.4 \text{ lbs/hp/hr}\)

The above assumptions and the mission specifications, given
in Table 3.1.2, yielded the airplane weights and
sensitivities in Table 3.1.3. Appendix H, section H.2
contains output from XEWTOG, a computerized weight sizing
method developed at the University of Kansas.

3.1.1.2 INITIAL PERFORMANCE SIZING

XPRFRM, a computer program developed at the University
of Kansas, was used to determine the required take-off power,
P_{TO} and wing area, S that meet the performance criteria given
in Table 3.1.2. XPRFRM follows the method of Reference 1.
Maximum lift coefficients and wing aspect ratio are also
determined. Figure 3.1.2 shows the required power loading,
wing loading combinations that satisfy the performance
criteria. From Figure 3.1.2 it is determined that cruise
speed and landing field length requirements are critical for
this airplane. The results of the performance sizing effort
are listed in Table 3.1.2. Appendix H, section H.3 details
the computer output of XPRFRM.

ORIGINAL PAGE IS
OF POOR QUALITY
### TABLE 3.1.1  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>421</td>
<td>69</td>
<td>170</td>
</tr>
<tr>
<td>$b$ ft</td>
<td>71.1</td>
<td>16.6</td>
<td>14</td>
</tr>
<tr>
<td>$c$ ft</td>
<td>6.28</td>
<td>4.2</td>
<td>13.33</td>
</tr>
<tr>
<td>$c_{LE}$ F.S.</td>
<td>487 in</td>
<td>962 in</td>
<td>795 in</td>
</tr>
<tr>
<td>$A$</td>
<td>12</td>
<td>4</td>
<td>1.15</td>
</tr>
<tr>
<td>$A_{LE}$</td>
<td>15°</td>
<td>20°</td>
<td>54°</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>.4</td>
<td>.7</td>
<td>.3</td>
</tr>
<tr>
<td>$t/c$</td>
<td>.13 root</td>
<td>.11</td>
<td>.11</td>
</tr>
<tr>
<td>Airfoil</td>
<td>NLF</td>
<td>NLF (sym)</td>
<td>NLF (sym)</td>
</tr>
<tr>
<td>$\Gamma$</td>
<td>7°</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>$i$</td>
<td>0°</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td></td>
<td>elevator chord ratio .36</td>
<td>rudder chord ratio .35</td>
<td></td>
</tr>
</tbody>
</table>

**Spoilers:** chord ratio .08  
span ratio .50 to .90  

**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>69.4</td>
<td>22.9</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>
</tr>
</tbody>
</table>
FIGURE 3.1.1 3-VIEW OF THE 85 PASSENGER MODEL
TABLE 3.1.2 MISSION SPECIFICATION FOR A 25 PASSENGER ADVANCED TECHNOLOGY COMMUTER AIRPLANE

| PAYLOAD: | 25 passengers at 175 lbs each with 30 lbs of baggage per passenger, carry-on luggage capability is required |
| CREW: | 2 pilots at 175 lbs each with 30 lbs of baggage each |
| RANGE: | 1100 nm with maximum payload with 25% fuel reserves |
| ALTITUDE: | 30,000 ft at the design range |
| CRUISE SPEED: | Mach = 0.70 |
| CLIMB: | climb rate of 3000 fpm |
| TAKE-OFF AND LANDING: | 3500 ft balanced field length |
| POWERPLANTS: | advanced turboprops |
| PRESSURIZATION: | 5000 ft cabin at 30,000 ft |
| CERTIFICATION BASE: | FAR 25 |

MISSION PROFILE:

1. TAKE-OFF
2. ENGINE START-UP
3. CLIMB
4. CRUISE
5. Descent
6. LANDING, TAXI AND SHUTDOWN
### TABLE 3.1.3 INITIAL SIZING PARAMETERS FOR THE 25 PASSENGER COMMUTER

Weights:

- Take-off Weight: \( W_{TO} = 21046 \text{ lbs} \)
- Operating Weight Empty: \( W_{OE} = 12154 \text{ lbs} \)
- Payload Weight: \( W_{PL} = 5125 \text{ lbs} \)
- Crew Weight: \( W_{CREW} = 410 \text{ lbs} \)
- Mission Fuel Weight: \( W_{F} = 3767 \text{ lbs} \)

Wing Area: \( S = 421 \text{ ft}^2 \)
Wing Aspect Ratio: \( A = 12 \)
Take-off Power: \( P_{TO} = 8419 \text{ shp} \)

Required Lift Coefficients:

- Clean \( C_{L\text{MAX}} = 1.4 \)
- Take-off \( C_{L\text{MAX}} = 1.4 \)
- Landing \( C_{L\text{MAX}} = 2.2 \)

Take-off Weight Sensitivities:

\[
\frac{\Delta W_{TO}}{\Delta C_{p}} = 20026.3 \text{ (lb/lb/hp/hr)}
\]
\[
\frac{\Delta W_{TO}}{\Delta \eta_p} = -9424.2 \text{ (lbs)}
\]
\[
\frac{\Delta W_{TO}}{\Delta (L/D)} = -500.7 \text{ (lbs)}
\]
\[
\frac{\Delta W_{TO}}{\Delta R} = 7.3 \text{ (lb/nm)}
\]

### 3.1.2 FUSELAGE AND COCKPIT LAYOUTS

The 25 passenger airplane has the same flight deck layout and fuselage cross section as the rest of the commuter family. The cockpit design and the fuselage cross section are contained in Appendix A. The lengths of the fuselage and cabin are given in Table 3.1.1.

The design methodology followed the steps in Reference 2. and 3.

### 3.1.3 ENGINE SELECTION

The commuter family will be powered by 2 advanced turboprop engines. The 25 passenger requires the use of two 6000 shp turboprops.

Appendix B contains engine data for the airplane.
FIGURE 3.1.2
PERFORMANCE MATCHING OF
THE 25 PASSENGER MODEL
3.1.4 WING AND FLAP DESIGN

Table 3.1.1 presents the geometry of the wing and flaps. Parameters such as leading edge sweep and wing thickness were dictated by the selection of an NLF airfoil. Appendix C contains the airfoil cross section and airfoil parameters. Wing parameters were selected using the method of Reference 2. chapter 6.

The flaps were sized to a $\frac{C_{L}}{C_{MAX}} = 2.2$. This required the use of Fowler flaps. The sizing methods used are contained in chapter 7 of Reference 2. The design calculations are in Appendix H, section H.4.

3.1.5 DESIGN OF THE EMPENNAGE

Table 3.1.1 shows the empennage for the 25 passenger airplane. Initially the V-bar method of chapter 8 in Reference 2. was used to size the empennage. The design calculations are in Appendix H, section H.5. The initial tail areas that resulted are listed below:

$$S_H = 51 \text{ ft}^2$$
$$S_V = 57 \text{ ft}^2$$

The empennage was redesigned from stability and control considerations. These considerations are discussed in section 3.1.9.

3.1.6 CONTROL SURFACE SIZING

3.1.6.1 LATERAL - DIRECTIONAL CONTROLS

Since full span flaps were required for landing, spoilers were used in place of ailerons. The spoiler geometry was determined from chapter 8 of Reference 2. Spoiler geometry is contained in Table 3.1.1. The rudder was also sized from methods in chapter 8 of Reference 2. Its geometry is contained in Table 3.1.1.

3.1.6.2 LONGITUDINAL CONTROLS

The elevators were sized using methods in chapter 8 of Reference 2. The geometry of the elevator is contained in Table 3.1.1.

3.1.7 LANDING GEAR DESIGN

From Reference 2. chapter 9. it was determined that a 30" x 9" tire could be utilized for the nose and main landing gear on every airplane of the commuter family. A preliminary retraction scheme for the main gear is shown in Appendix D. The gear placement was dictated by the weight and balance.
calculations shown in section 3.1.8. Lateral tip-over, and longitudinal gear placement criteria given in Reference 2, were met. Appendix H, section H.6 contains the lateral tip-over calculations.

3.1.8 CLASS I WEIGHT AND BALANCE CALCULATIONS

Class I component weights were calculated by averaging typical take-off weight fractions of commuter airplanes. Appendix F contains the class I weight fractions for the commuter family. Using methods in chapter 10 of Reference 2, a preliminary weight and balance of the 25 passenger commuter was determined. Component weights and center of gravity locations are contained in Table 3.1.4. A general arrangement drawing is contained in Figure 3.1.3. The center of gravity excursion diagram is contained in Figure 3.1.4. The 25 passenger commuter has a 13.4" excursion range. This is \( C_w \).

3.1.9 STABILITY AND CONTROL RESULTS

A class I stability and control analysis was performed using the methods of Reference 2, chapter 11. Table 3.1.5 contains geometric quantities and stability derivatives necessary to size the empennage from stability and control considerations. Design calculations are located in Appendix H, section H.7.

3.1.9.1 LONGITUDINAL STABILITY

From methods in chapter 11 of Reference 2, the horizontal tail was resized to incorporate a desired static margin of 5%. Appendix H, Figure H.2 presents the longitudinal X-plot for the airplane. From this plot it is seen that a tail area of 66 ft\(^2\) is required. Because this required horizontal tail area is very similar to that required for the 36 passenger configuration, it was decided to implement the tail required for the 36 passenger airplane on both configurations. This is a very acceptable compromise between performance requirements and commonality.

3.1.9.2 LATERAL - DIRECTIONAL STABILITY

From methods in chapter 11 of Reference 2, the vertical tail area required to hold engine-out flight was determined to be critical. Appendix H, section H.7 details the engine-out calculations. The engines were put at a five degree cant to lessen the thrust moment arm about the C.G. This allowed
## TABLE 3.1.4 25 PASSENGER COMMUTER
**CLASS I WEIGHT AND BALANCE CALCULATION**

<table>
<thead>
<tr>
<th>#</th>
<th>COMPONENT</th>
<th>( W_i )</th>
<th>( x_i )</th>
<th>( W_i x_i )</th>
<th>( z_i )</th>
<th>( W_i z_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fuselage</td>
<td>2526</td>
<td>487</td>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Wing</td>
<td>2294</td>
<td>520</td>
<td>110</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Empennage</td>
<td>568</td>
<td>920</td>
<td>252</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Engine</td>
<td>2526</td>
<td>520</td>
<td>232</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Nose Gear</td>
<td>288</td>
<td>250</td>
<td>65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Main Gear</td>
<td>575</td>
<td>550</td>
<td>65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Fixed eqpt.</td>
<td>2862</td>
<td>487</td>
<td>124</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Empty Weight:** \( W_e = 11639 \)  
\[
\begin{align*}
X_{cg_{we}} &= 519 \\
Z_{cg_{we}} &= 146
\end{align*}
\]

| 7  | Trp. fuel/oil | 105 | 555 | 110 |          |               |
| 8  | Crew         | 410 | 195 | 124 |          |               |

**Operating Weight Empty:** \( W_{OE} = 12154 \)  
\[
\begin{align*}
X_{cg_{woe}} &= 508 \\
Z_{cg_{woe}} &= 145
\end{align*}
\]

| 9  | Fuel        | 3767 | 520 | 110 |          |               |
|    |             |      |     |     |          |               |
\[
W_{OE} + W_F = 15921
\]
\[
X_{cg_{woe+wF}} = 511
\]

| 10 | Passengers  | 5125 | 472 | 124 |          |               |
|    |             |      |     |     |          |               |
\[
W_{OE} + W_{pax} = 17279
\]
\[
X_{cg_{woe+wpax}} = 498
\]

**Take-off Weight: ** \( W_{TO} = 21046 \)  
\[
\begin{align*}
X_{cg_{wto}} &= 502 \\
Z_{cg_{wto}} &= 133
\end{align*}
\]
ORIGINAL PAGE IS OF POOR QUALITY

FIGURE 3.1.4 CENTER OF GRAVITY EXCURSION DIAGRAM OF THE 25 PASSENGER MODEL

UNIVERSITY OF KANSAS
### TABLE 3.1.5 STABILITY AND CONTROL RESULTS FOR THE 25 PASSENGER COMMUTER

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S$</td>
<td>421 ft²</td>
</tr>
<tr>
<td>$c$</td>
<td>6.28 ft</td>
</tr>
<tr>
<td>$b$</td>
<td>71.1 ft</td>
</tr>
<tr>
<td>$S_H$</td>
<td>69 ft²</td>
</tr>
<tr>
<td>$S_V$</td>
<td>170 ft²</td>
</tr>
<tr>
<td>$\Delta x_{AC_B}$</td>
<td>-.34</td>
</tr>
<tr>
<td>$x_{AC_WB}$</td>
<td>-.09</td>
</tr>
<tr>
<td>$x_{AC_A}$</td>
<td>.45</td>
</tr>
<tr>
<td>$x_{AC_H}$</td>
<td>6.30</td>
</tr>
<tr>
<td>$C_{L_{\alpha_W}}$</td>
<td>4.71 rad⁻¹</td>
</tr>
<tr>
<td>$C_{L_{\alpha_H}}$</td>
<td>3.41 rad⁻¹</td>
</tr>
<tr>
<td>$C_{L_{\alpha_V}}$</td>
<td>1.46 rad⁻¹</td>
</tr>
<tr>
<td>$C_{n_B}$</td>
<td>0.084 rad⁻¹</td>
</tr>
<tr>
<td>$\frac{dx}{d\alpha}$</td>
<td>0.22</td>
</tr>
<tr>
<td>$x_{CG_{aft}}$</td>
<td>.32</td>
</tr>
<tr>
<td>$X_V$</td>
<td>31.4 ft</td>
</tr>
</tbody>
</table>

*All results calculated from References 5. and 6.*
for a vertical tail area of 170 ft$^2$. Appendix H, Figure H.3 contains a directional X-plot for the airplane. It can be seen that 170 ft$^2$ vertical tail yields a $c_B = 0.0015$ deg$^{-1}$.

### 3.1.10 CLASS I DRAG POLARS

From methods in Reference 2 chapter 12, component wetted areas were calculated. See Table 3.1.6 and Appendix H, section H.8. From the total airplane wetted area and assuming a skin friction coefficient of 0.0025, $C_D$ for the airplane was calculated. Table 3.1.7 contains the take-off, cruise, and landing drag polars computed during the initial performance sizing. These drag polars are compared to the drag polars computed from wetted area considerations. These class I drag polars more accurately represent the airplane. Changes to $C_D$ for take-off and landing polars are given in Appendix H, section H.8.

#### TABLE 3.1.6 WETTED AREA BREAKDOWN

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>WETTED AREA (ft$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing</td>
<td>717</td>
</tr>
<tr>
<td>Horizontal Tail</td>
<td>142</td>
</tr>
<tr>
<td>Vertical Tail</td>
<td>349</td>
</tr>
<tr>
<td>Fuselage</td>
<td>1471</td>
</tr>
<tr>
<td>Engine Nacelles</td>
<td>90x2</td>
</tr>
<tr>
<td>Engine Pylons</td>
<td>80</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2939</strong></td>
</tr>
</tbody>
</table>

From Figure 3.21 Reference 1, assuming a $c_f = 0.0025$.

\[ f = 7.2 \text{ ft}^2 \]

\[ C_D = f/S_{\text{ref}} = 7.2/421 = 0.0171 \]

Now the drag polars can be calculated.

#### TABLE 3.1.7 DRAG POLAR COMPARISON

<table>
<thead>
<tr>
<th>FLIGHT CONDITION</th>
<th>INITIAL (L/D)$_{\text{max}}$</th>
<th>CLASS I (L/D)$_{\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take-off</td>
<td>$C_D = 0.0362 + 0.0332 C_L^2$</td>
<td>$C_D = 0.0321 + 0.0332 C_L^2$</td>
</tr>
<tr>
<td></td>
<td>14.4</td>
<td>15.3</td>
</tr>
<tr>
<td>Cruise</td>
<td>$C_D = 0.0162 + 0.0312 C_L^2$</td>
<td>$C_D = 0.0173 + 0.0312 C_L^2$</td>
</tr>
<tr>
<td></td>
<td>22.2</td>
<td>21.5</td>
</tr>
<tr>
<td>Landing</td>
<td>$C_D = 0.0662 + 0.0332 C_L^2$</td>
<td>$C_D = 0.1071 + 0.0332 C_L^2$</td>
</tr>
<tr>
<td></td>
<td>10.7</td>
<td>8.4</td>
</tr>
</tbody>
</table>
Assuming a $C_L^{CR} = .3$

$(L/D)^{CR} = 14.9$

During initial take-off weight sizing $(L/D)^{CR}$ was assumed to be 16.

The sensitivities to $W_{TO}$ given in Table 3.1.3 show that:

$$\frac{\Delta W_{TO}}{\Delta (L/D)^{CR}} = -500.7 \text{ lbs}$$

Therefore for the baseline configuration:

$$\Delta (L/D)^{CR} = 14.9 - 16 = -1.1$$

$$\Delta W_{TO} = \Delta (L/D)^{CR} \frac{\Delta W_{TO}}{\Delta (L/D)^{CR}} = 551 \text{ lbs}$$

Since $W_{TO} = 21046 \text{ lbs}$, the reduction in $(L/D)^{CR}$ causes a 2.6% increase in $W_{TO}$. This small change does not warrant resizing of the airplane take-off weight.
3.2 PRELIMINARY DESIGN OF THE 36 PASSENGER
BASELINE CONFIGURATION

Figure 3.2.1 contains the class I 3-view for the 36
passenger commuter. Table 3.2.1 contains the geometry of the
configurations

3.2.1 INITIAL WEIGHT AND PERFORMANCE SIZING FOR THE 36
PASSENGER BASELINE CONFIGURATION

3.2.1.1 INITIAL WEIGHT SIZING

Initial weight sizing was conducted using a method in
Reference 1. The following assumptions were made for the
airplane:

1) \( \frac{L}{D} \) \(_{cr} = 16 \)
2) \( C_D = 0.4 \) lbs/hp/hr

The above assumptions and the mission specifications, given
in Table 3.2.2, yielded the airplane weights and
sensitivities in Table 3.2.3. Appendix I, section 1.2
contains output from XEWTOG, a computerized weight sizing
method developed at the University of Kansas.

3.2.1.2 INITIAL PERFORMANCE SIZING

XPRFRM, a computer program developed at the University
of Kansas, was used to determine the required take-off power,
\( P_{TO} \) and wing area, \( S \) that meet the performance criteria given
in Table 3.2.2. XPRFRM follows the method of Reference 1.
Maximum lift coefficients and wing aspect ratio are also
determined. Figure 3.2.2 shows the required power loading,
wing loading combinations that satisfy the performance
criteria. From Figure 3.2.2 it is determined that cruise
speed and landing field length requirements are critical for
this airplane. The results of the performance sizing effort
are listed in Table 3.2.2. Appendix I, section 1.3 details
the computer output of XPRFRM.
### TABLE 3.2.1 TABLE OF GEOMETRY FOR THE 36 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>449</td>
<td>69</td>
<td>130</td>
</tr>
<tr>
<td>$b$ ft</td>
<td>73.4</td>
<td>16.6</td>
<td>12</td>
</tr>
<tr>
<td>$c$ ft</td>
<td>6.5</td>
<td>4.2</td>
<td>11.88</td>
</tr>
<tr>
<td>$c$ LE F.S.</td>
<td>571</td>
<td>1080</td>
<td>938</td>
</tr>
<tr>
<td>$A$</td>
<td>12</td>
<td>4</td>
<td>1.1</td>
</tr>
<tr>
<td>$\Lambda$ LE</td>
<td>15°</td>
<td>20°</td>
<td>58°</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>.4</td>
<td>.7</td>
<td>.3</td>
</tr>
<tr>
<td>$t/c$</td>
<td>.13 root</td>
<td>.11</td>
<td>.11</td>
</tr>
<tr>
<td>Airfoil</td>
<td>NLF</td>
<td>NLF (sym)</td>
<td>NLF (sym)</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>7°</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>$i$</td>
<td>3°</td>
<td>0°</td>
<td>0°</td>
</tr>
</tbody>
</table>

- Elevator chord ratio: .36
- Rudder chord ratio: .35

**Spoilers:**
- Chord ratio: .12
- Span ratio: .58 to .88

**Flaps:**
- Chord ratio: .25
- 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>
<td>78.1</td>
<td>36.7</td>
<td>86.0</td>
</tr>
<tr>
<td>Height in</td>
<td>96</td>
<td>76</td>
<td>290</td>
</tr>
<tr>
<td>Width in</td>
<td>96</td>
<td>91</td>
<td>881</td>
</tr>
</tbody>
</table>
FIGURE 3.2.1 3-VIEW OF THE 36 PASSENGER MODEL
### Table 3.2.2 Mission Specification for a 36 Passenger Advanced Technology Commuter Airplane

<table>
<thead>
<tr>
<th>Specification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload:</td>
<td>36 passengers at 175 lbs each with 30 lbs of baggage per passenger, carry-on luggage capability is required</td>
</tr>
<tr>
<td>Crew:</td>
<td>2 pilots and 1 flight attendant at 175 lbs each with 30 lbs of baggage each</td>
</tr>
<tr>
<td>Range:</td>
<td>1100 nm with maximum payload with 25% fuel reserves</td>
</tr>
<tr>
<td>Altitude:</td>
<td>30,000 ft at the design range</td>
</tr>
<tr>
<td>Cruise Speed:</td>
<td>Mach = 0.70</td>
</tr>
<tr>
<td>Climb:</td>
<td>Climb rate of 3000 fpm</td>
</tr>
<tr>
<td>Take-Off and Landing:</td>
<td>3500 ft balanced field length</td>
</tr>
<tr>
<td>Powerplants:</td>
<td>Advanced turboprops</td>
</tr>
<tr>
<td>Pressurization:</td>
<td>5000 ft cabin at 30,000 ft</td>
</tr>
<tr>
<td>Certification Base:</td>
<td>FAR 25</td>
</tr>
</tbody>
</table>

**Mission Profile:**

1. Take-Off Engine Start-Up
2. Climb
3. Cruise
4. Climb
5. Descent
6. Landing, Taxi, and Shutdown
TABLE 3.2.3 INITIAL SIZING PARAMETERS FOR THE 36 PASSENGER COMMUTER

Weights: Take-off Weight - \( W_{TO} = 31395 \text{ lbs} \)
Operating Weight Empty - \( W_{OE} = 18395 \text{ lbs} \)
Payload Weight - \( W_{PL} = 7380 \text{ lbs} \)
Crew Weight - \( W_{CREW} = 615 \text{ lbs} \)
Mission Fuel Weight - \( W_{F} = 5620 \text{ lbs} \)

Wing Area - \( S = 449 \text{ ft}^2 \)
Wing Aspect Ratio - \( A = 12 \)
Take-off Power - \( P_{TO} = 8970 \text{ shp} \)

Required Lift Coefficients -

\[
\begin{align*}
\text{Clean} & \quad C_{L}^{\text{MAX}} = 1.4 \\
\text{Take-off} & \quad C_{L}^{\text{MAX}} = 1.4 \\
\text{Landing} & \quad C_{L}^{\text{MAX}} = 3.0
\end{align*}
\]

Take-off Weight Sensitivities -

\[
\begin{align*}
\frac{\partial W_{TO}}{\partial C_{P}} &= 30976.4 \text{ (lb/lb/hp/hr)} \\
\frac{\partial W_{TO}}{\partial n_{P}} &= -14577.1 \text{ (lbs)} \\
\frac{\partial W_{TO}}{\partial (L/D)} &= -744.4 \text{ (lbs)} \\
\frac{\partial W_{TO}}{\partial R} &= 11.3 \text{ (lb/nm)}
\end{align*}
\]

3.2.2 FUSELAGE AND COCKPIT LAYOUTS

The 36 passenger airplane has the same flight deck layout and fuselage cross section as the rest of the commuter family. The cockpit design and the fuselage cross section are contained in Appendix A. The lengths of the fuselage and cabin are given in Table 3.2.1.

The design methodology followed the steps in Reference 2. and 3.
3.2.3 ENGINE SELECTION

The commuter family will be powered by 2 advanced turboprop engines. The 36 passenger requires the use of two 6000 shp turboprops.

Appendix B contains engine data for the airplane.

3.2.4 WING AND FLAP DESIGN

Table 3.2.1 presents the geometry of the wing and flaps. Parameters such as leading edge sweep and wing thickness were dictated by the selection of an NLF Airfoil. Appendix C contains the airfoil cross section and airfoil parameters. Wing parameters were selected using the method of Reference 2. chapter 6.

The flaps were sized to a $C_L = 3.0$. This required the use of fowler flaps. The sizing methods used are contained in chapter 7 of Reference 2. The design calculations are in Appendix I, section I.4.

3.2.5 DESIGN OF THE EMPENNAGE

Table 3.2.1 shows the empennage for the 36 passenger airplane. Initially the V-bar method of chapter 8 in Reference 2. was used to size the empennage. The design calculations are in Appendix I, section I.5. The initial tail areas that resulted are listed below:

- $S_H = 69$ ft$^2$
- $S_V = 78$ ft$^2$

The empennage was redesigned from stability and control considerations. These considerations are discussed in section 3.2.9.

3.2.6 CONTROL SURFACE SIZING

3.2.6.1 LATERAL - DIRECTIONAL CONTROLS

Since full span flaps were required for landing, spoilers were used in place of ailerons. The spoiler geometry was determined from chapter 8 of Reference 2. Spoiler geometry is contained in Table 3.2.1. The rudder was also sized from methods in chapter 8 of Reference 2. Its geometry is contained in Table 3.2.1.

3.2.6.2 LONGITUDINAL CONTROLS

The elevators were sized using methods in chapter 8 of Reference 2. The geometry of the elevator is contained in Table 3.2.1
From Reference 2, chapter 9, it was determined that a 30" x 9" tire could be utilized for the nose and main landing gear on every airplane of the commuter family. A preliminary retraction scheme for the main gear is shown in Appendix D. The gear placement was dictated by the weight and balance calculations shown in section 3.2.8. Lateral tip-over, and longitudinal gear placement criteria given in Reference 2, were met. Appendix I, section I.6 contains the lateral tip-over calculations.

3.2.8 CLASS I WEIGHT AND BALANCE CALCULATIONS

Class I component weights were calculated by averaging typical take-off weight fractions of commuter airplanes. Appendix F contains the class I weight fractions for the commuter family. Using methods in chapter 10 of Reference 2, a preliminary weight and balance of the 36 passenger commuter was determined. Component weights and center of gravity locations are contained in Table 3.2.4. A general arrangement drawing is contained in Figure 3.2.3. The center of gravity excursion diagram is contained in Figure 3.2.4. The 36 passenger commuter has a 22" excursion range. This is .28 $C_w$.

3.2.9 STABILITY AND CONTROL RESULTS

A class I stability and control analysis was performed using the methods of Reference 2, chapter 11. Table 3.2.5 contains geometric quantities and stability derivatives necessary to size the empennage from stability and control considerations. Design calculations are located in Appendix I, section I.7.

3.2.9.1 LONGITUDINAL STABILITY

From methods in chapter 11 of Reference 2, the horizontal tail was resized to incorporate a desired static margin of 5%. Appendix I, Figure 1.2 presents the longitudinal X-plot for the airplane. From this plot it is seen that a tail area of 62 ft$^2$ is required. Since 69 ft$^2$ was the original estimate, it was decided that not enough area change occurred to warrant resizing the horizontal tail.

3.2.9.2 LATERAL - DIRECTIONAL STABILITY

From methods in chapter 11 of Reference 2, the vertical tail area required to hold engine-out flight was determined to be critical. Appendix I, section I.7 details the engine-out calculations. The engines were put at a five degree cant.
FIGURE 3.2.3 36 PASSENGER GENERAL ARRANGEMENT
### TABLE 3.2.4 36 PASSENGER COMMUTER CLASS I WEIGHT AND BALANCE CALCULATION

<table>
<thead>
<tr>
<th>#</th>
<th>COMPONENT</th>
<th>( W_i )</th>
<th>( x_i )</th>
<th>( W_i x_i )</th>
<th>( z_i )</th>
<th>( W_i z_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Fuselage</td>
<td>3767</td>
<td>541</td>
<td>191</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Wing</td>
<td>3422</td>
<td>610</td>
<td>208</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Empennage</td>
<td>847</td>
<td>1045</td>
<td>320</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Engine</td>
<td>4105</td>
<td>700</td>
<td>276</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Nose Gear</td>
<td>429</td>
<td>125</td>
<td>137</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Main Gear</td>
<td>858</td>
<td>620</td>
<td>137</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Fixed eqpt.</td>
<td>4270</td>
<td>525</td>
<td>191</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Empty Weight: \( W_e = 17698 \)  
\[ 10741347 \]  
\[ X_{c_g_{w_e}} = 607 \]  
\[ Z_{c_g_{w_e}} = 208 \]  

7. Trp. fuel/oil 82 655  
8. Crew 615 200  

Operating Weight Empty: \( W_{OE} = 18395 \)  
\[ 10918057 \]  
\[ X_{c_g_{w_{OE}}} = 594 \]  
\[ Z_{c_g_{w_{OE}}} = 207 \]  

9. Fuel 5620 605  
\[ W_{OE} + W_F = 24015 \]  
\[ 14318157 \]  
\[ X_{c_g_{w_{OE}+wF}} = 596 \]  

10. Passengers 7380 525  
\[ W_{OE} + W_{pax} = 25775 \]  
\[ 14792557 \]  
\[ X_{c_g_{w_{OE}+wpax}} = 574 \]  

Take-off Weight: \( W_{TO} = 31395 \)  
\[ 18192657 \]  
\[ X_{c_g_{w_{TO}}} = 579 \]  
\[ Z_{c_g_{w_{TO}}} = 196 \]
TABLE 3.2.5 STABILITY AND CONTROL RESULTS FOR THE
36 PASSENGER COMMUTER

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S = 449 , \text{ft}^2 )</td>
<td></td>
</tr>
<tr>
<td>( \bar{c} = 6.5 , \text{ft} )</td>
<td></td>
</tr>
<tr>
<td>( b = 73.4 , \text{ft} )</td>
<td></td>
</tr>
<tr>
<td>( S_H = 69 , \text{ft}^2 )</td>
<td></td>
</tr>
<tr>
<td>( S_V = 130 , \text{ft}^2 )</td>
<td></td>
</tr>
<tr>
<td>( \Delta \bar{x}_{AC_B} = -0.33 )</td>
<td></td>
</tr>
<tr>
<td>( \bar{x}<em>{AC</em>{WB}} = -0.08 )</td>
<td></td>
</tr>
<tr>
<td>( \bar{x}_{AC_A} = 0.43 )</td>
<td>F.S. 604</td>
</tr>
<tr>
<td>( \bar{x}_{AC_H} = 6.40 )</td>
<td></td>
</tr>
<tr>
<td>( C_{L_{\alpha_W}} = 4.71 , \text{rad}^{-1} )</td>
<td></td>
</tr>
<tr>
<td>( C_{L_{\alpha_H}} = 3.41 , \text{rad}^{-1} )</td>
<td></td>
</tr>
<tr>
<td>( C_{L_{\alpha_V}} = 1.46 , \text{rad}^{-1} )</td>
<td></td>
</tr>
<tr>
<td>( C_{n_B} = 0.178 , \text{rad}^{-1} )</td>
<td></td>
</tr>
<tr>
<td>( \frac{d\bar{C}}{d\alpha} = 0.236 )</td>
<td></td>
</tr>
<tr>
<td>( \bar{x}<em>{CG</em>{\text{aft}}} = 0.33 )</td>
<td>F.S. 597</td>
</tr>
<tr>
<td>( X_V = 34.67 , \text{ft} )</td>
<td></td>
</tr>
</tbody>
</table>

*All results calculated from References 5. and 6.*
to lessen the thrust moment arm about the C.G. This allowed for a vertical tail area of 130 ft². Appendix I, Figure I.3 contains a directional X-plot for the airplane. It can be seen that 130 ft² vertical tail yields a \( c_{n_b} = 0.0030 \) deg\(^{-1}\).

### 3.2.10 CLASS I DRAG POLARS

From methods in Reference 2 chapter 12, component wetted areas were calculated. See Table 3.2.6 and Appendix I, section I.8. From the total airplane wetted area and assuming a skin friction coefficient of 0.0025, \( C_D \) for the airplane was calculated. Table 3.2.7 contains the take-off, cruise, and landing drag polars computed during the initial performance sizing. These drag polars are compared to the drag polars computed from wetted area considerations. These class I drag polars more accurately represent the airplane. Changes to \( C_D \) for take-off and landing polars are given in Appendix I, section I.8.

#### TABLE 3.2.6 WETTED AREA BREAKDOWN

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>WETTED AREA (ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing</td>
<td>788</td>
</tr>
<tr>
<td>Horizontal Tail</td>
<td>142</td>
</tr>
<tr>
<td>Vertical Tail</td>
<td>267</td>
</tr>
<tr>
<td>Fuselage</td>
<td>1702</td>
</tr>
<tr>
<td>Engine Nacelles</td>
<td>90x2</td>
</tr>
<tr>
<td>Engine Pylons</td>
<td>62x2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3203</strong></td>
</tr>
</tbody>
</table>

From Figure 3.21 Reference 1, assuming a \( c_f = 0.0025 \).

\[
f = 7.8 \text{ ft}^2
\]

\[
C_D = \frac{f}{S_{ref}} = \frac{7.8}{449} = 0.0174
\]

Now the drag polars can be calculated.

#### TABLE 3.2.7 DRAG POLAR COMPARISON

<table>
<thead>
<tr>
<th>FLIGHT CONDITION</th>
<th>INITIAL</th>
<th>( C_D ) ( C_L ) \text{ max}</th>
<th>( C_D ) ( C_L ) \text{ max}</th>
<th>( C_D ) ( C_L ) \text{ max}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take-off</td>
<td>( C_D = 0.0408 + 0.0332 ) ( C_L^2 ) 13.6</td>
<td>( C_D = 0.0324 + 0.0332 ) ( C_L^2 ) 15.2</td>
<td>( C_D = 0.0324 + 0.0332 ) ( C_L^2 ) 15.2</td>
<td></td>
</tr>
<tr>
<td>Cruise</td>
<td>( C_D = 0.0241 + 0.0312 ) ( C_L^2 ) 18.2</td>
<td>( C_D = 0.0176 + 0.0312 ) ( C_L^2 ) 21.3</td>
<td>( C_D = 0.0176 + 0.0312 ) ( C_L^2 ) 21.3</td>
<td></td>
</tr>
<tr>
<td>Landing</td>
<td>( C_D = 0.1076 + 0.0332 ) ( C_L^2 ) 8.4</td>
<td>( C_D = 0.1074 + 0.0332 ) ( C_L^2 ) 8.4</td>
<td>( C_D = 0.1074 + 0.0332 ) ( C_L^2 ) 8.4</td>
<td></td>
</tr>
</tbody>
</table>
Assuming \( C_{L_{CR}} = 0.3 \)
\[(L/D)_{CR} = 14.7\]

During initial take-off weight sizing \((L/D)_{CR}\) was assumed to be 16.

The sensitivities to \( W_{TO} \) given in Table 3.2.3 show that:
\[
\frac{\Delta W_{TO}}{\Delta (L/D)} = -744.4 \text{ lbs}
\]

Therefore for the baseline configuration:
\[
\Delta (L/D)_{CR} = 14.7 - 16 = -1.3
\]
\[
\Delta W_{TO} = \Delta (L/D)_{CR} \frac{\Delta W_{TO}}{\Delta (L/D)} = 968 \text{ lbs}
\]

Since \( W_{TO} = 31395 \text{ lbs} \), the reduction in \((L/D)_{CR}\) causes a 3% increase in \( W_{TO} \). This 3% change does not warrant resizing of the airplane take-off weight.
3.3 PRESENTATION OF THE 75 PASSENGER TWIN-BODY CONFIGURATION

This section presents the class I design of a 75 passenger twin-body configuration. A class I 3-view is shown in Figure 3.3.1, with the corresponding geometric data in Table 3.3.1. The most significant advantage of this configuration is commonality. Major components of the 36 passenger design are used in the 75 passenger twin-body configuration:

- Common
- Fuselage
- Wing (outboard section)
- Vertical Tail
- Horizontal Tail
- Cockpit

3.3.1 INITIAL WEIGHT AND PERFORMANCE SIZING FOR THE 75 TWIN-BODY BASELINE CONFIGURATION

3.3.1.1 INITIAL WEIGHT SIZING

The weight sizing methods in Reference 1. are empirical, using data from past airplanes. Since a data base on twin-body airplanes is nearly non-existent, this method was not used. To estimate the twin-body weight the 36 passenger airplane weights were doubled. Then adjustments for specific components were made:

- Wing: -1920 lbs (lighter center section)
- Engines: +260 lbs (larger engines)
- Fixed Equipment: -801 lbs (1 cockpit)

Total Reduction: -2461 lbs

The mission specification and a typical mission profile are given in Table 3.3.2. Mission weights and performance estimates are presented in Table 3.3.3.

3.3.2 FUSELAGE AND COCKPIT LAYOUTS

The 75 passenger twin-body configuration will use only one cockpit. The space allotted for the cockpit in the second fuselage will be replaced with passenger seats. The cockpit and fuselage cross sections are common with the other airplanes in the commuter family. These cross sections are shown in Appendix A. Fuselage and cabin dimensions are given in Table 3.3.1.

3.3.3 ENGINE SELECTION

The twin-body configuration had the possibility of using 3 engines. However, a suitable engine arrangement with 3 engines was not found, so 2 larger engines were used. Using
## TABLE 3.3.1 TABLE OF GEOMETRY FOR THE 75 PASSENGER TWIN-BODY CONFIGURATION

<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>722</td>
<td>2x102</td>
<td>2x130</td>
</tr>
<tr>
<td>b ft</td>
<td>104.5</td>
<td>22.6</td>
<td>12</td>
</tr>
<tr>
<td>c ft</td>
<td>7.5</td>
<td>4.68</td>
<td>11.88</td>
</tr>
<tr>
<td>c LE F.S.</td>
<td>571</td>
<td>1080</td>
<td>938</td>
</tr>
<tr>
<td>A</td>
<td>15.1</td>
<td>5.0</td>
<td>1.1</td>
</tr>
<tr>
<td>A(_{LE})</td>
<td>15°</td>
<td>25°</td>
<td>58°</td>
</tr>
<tr>
<td>(\lambda)</td>
<td>.4</td>
<td>.50</td>
<td>.3</td>
</tr>
<tr>
<td>t/c</td>
<td>.13 root</td>
<td>.11</td>
<td>.11</td>
</tr>
<tr>
<td>Airfoil</td>
<td>NLF</td>
<td>NLF (sym)</td>
<td>NLF (sym)</td>
</tr>
<tr>
<td>(\Gamma)</td>
<td>7°</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>i</td>
<td>-</td>
<td>0°</td>
<td>0°</td>
</tr>
</tbody>
</table>

- elevator chord: rudder chord ratio .36 ratio .35
- Spoiler: chord ratio .12 span ratio .58 to .88 (outboard section)
- Flap: chord ratio .25 span ratio .11 to 1.0 (outboard section)

### FUSELAGE

<table>
<thead>
<tr>
<th></th>
<th>FUSELAGE</th>
<th>CABIN INTERIOR</th>
<th>OVERALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length ft</td>
<td>78.1</td>
<td>36.7</td>
<td>86.0</td>
</tr>
<tr>
<td>Height in</td>
<td>96</td>
<td>76</td>
<td>290</td>
</tr>
<tr>
<td>Width in</td>
<td>96</td>
<td>91</td>
<td>881</td>
</tr>
<tr>
<td><strong>MISSION SPECIFICATION FOR A 75 PASSENGER ADVANCED TECHNOLOGY COMMUTER AIRPLANE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PAYLOAD:</strong> 75 passengers at 175 lbs each with 30 lbs of baggage per passenger, carry-on luggage capability is required</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CREW:</strong> 2 pilots and 2 flight attendants at 175 lbs with 30 lbs of baggage each</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>RANGE:</strong> 1500 nm with maximum payload and 25% fuel reserves</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ALTITUDE:</strong> 30,000 ft at the design range</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CRUISE SPEED:</strong> Mach .70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CLIMB:</strong> climb rate of 3000 fpm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TAKE-OFF AND LANDING:</strong> 3500 ft balanced field length</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>POWERPLANTS:</strong> Advanced turboprops</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PRESSURIZATION:</strong> 5000 ft cabin at 30,000 ft</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CERTIFICATION BASE:</strong> FAR 25</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**MISSION SPECIFICATION:**

```
1. Take-off engine start-up
2. Climb
3. Cruise
4. Climb
5. Cruise
6. Descent
7. Landing, taxi and shutdown
```
TABLE 3.3.3 INITIAL SIZING PARAMETERS FOR THE 75 PASSENGER TWIN-BODY CONFIGURATION

Weights: Take-off Weight - $W_{TD} = 60683 \text{ lbs}$
Operating Weight Empty - $W_{OE} = 34068 \text{ lbs}$
Payload Weight - $W_{PL} = 15375 \text{ lbs}$
Crew Weight - $W_{CREW} = 820 \text{ lbs}$
Mission Fuel Weight - $W_F = 11240 \text{ lbs}$

Wing Area - $S = 722 \text{ ft}^2$
Wing Aspect Ratio - $A = 15.1$
Take-off Power - $P_{TO} = 18000 \text{ shp}$

Required Lift Coefficients -
- Clean $C_{L\text{MAX}} = 1.4$
- Take-off $C_{L\text{MAX}} = 1.4$
- Landing $C_{L\text{MAX}} = 3.0$

two engines also improves the possibility of complete cockpit commonality and pilot cross rating. Two 13500 shp engines will be used. Data for these engines is contained in Appendix B.

3.3.4 WING AND FLAP DESIGN

The wing of the 75 passenger twin-body may be broken into 2 outboard sections, and an inboard section. The two outboard sections are identical to the wing for the 36 passenger airplane (see section 3.2.4). The inboard section is a straight wing that joins the two fuselages at the wing boxes. This section also transmits loads, and damps vibrations, between the two fuselages.

To achieve a high lift coefficient for landing, full span fowler flaps along both inboard and outboard wings will be required.

Data for the outboard wings (36 passenger) are given in Table 3.2.1. The 75 passenger twin-body wing data is presented in Table 3.3.1. Appendix C contains airfoil section data for the NLF airfoil.

3.3.5 DESIGN OF THE EMPENNAGE

The empennage designed for the 36 passenger airplane will be used on each fuselage of the 75 passenger twin-body. This will increase the commonality between the two airplanes. Stability and control considerations for the 75 passenger
twin-body may require further modifications to the empennage, which are discussed in section 3.3.9.

3.3.6 CONTROL SURFACE SIZING

3.3.6.1 LATERAL – DIRECTIONAL CONTROLS

The lateral-directional controls used on the 36 passenger wing (spoilers) will also be used on the outboard 75 passenger twin-body wings. Although the moment of inertia for the twin-body is much greater, the distance of the spoilers from the C.G. is also larger. Additional lateral-directional control power may be required. Increasing the spoiler span may solve this problem. Spoiler geometries are given in Table 3.3.1.

3.3.6.2 LONGITUDINAL CONTROLS

The elevators used on the 36 passenger airplane will also be used on each of the horizontal tails. Elevator geometry is presented in Table 3.3.1.

3.3.7 LANDING GEAR DESIGN

As with the rest of the commuter family, a 30"x9" tire will be used for both main and nose gears. The gear location will be common with the 36 passenger airplane to retain commonality. Since the main gears are far from the C.G., lateral tip-over is not a concern. A gear retraction scheme is shown in Appendix D.

3.3.8 CLASS I WEIGHT AND BALANCE CALCULATIONS

A class I weight and balance calculation was done using the method of chapter 10 in Reference 2. The component weight estimates are listed in Table 3.3.4. Figure 3.3.2 shows the general arrangement and C.G. locations of the components in Table 3.3.4. There is a 23.7" (0.26 \( \bar{C}_W \)) C.G. travel range between \( W_{OE} \) and \( W_{OE} + W_{pax} \). The C.G. excursion diagram is shown in Figure 3.3.3.

3.3.9 STABILITY AND CONTROL RESULTS

Table 3.3.5 contains the geometric quantities and stability derivatives used in the stability and control calculations. The methods of chapter 11 in Reference 2 were used for the class I calculations. The design calculations are located in section M.2 of Appendix M.
### Table 3.3.4 75 Passenger Twin Body

#### Class I Weight and Balance Calculation

<table>
<thead>
<tr>
<th>Component</th>
<th>( W_i )</th>
<th>( x_i )</th>
<th>( W_i x_i )</th>
<th>( z_i )</th>
<th>( W_i z_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Fuselage</td>
<td>7534</td>
<td>541</td>
<td>4076000</td>
<td>191</td>
<td>1440000</td>
</tr>
<tr>
<td>2. Wing</td>
<td>4923</td>
<td>610</td>
<td>3003000</td>
<td>166</td>
<td>820000</td>
</tr>
<tr>
<td>3. Empennage</td>
<td>1695</td>
<td>1045</td>
<td>1771000</td>
<td>320</td>
<td>540000</td>
</tr>
<tr>
<td>4. Engine</td>
<td>8470</td>
<td>700</td>
<td>5929000</td>
<td>276</td>
<td>2340000</td>
</tr>
<tr>
<td>5. Nose Gear</td>
<td>858</td>
<td>195</td>
<td>167000</td>
<td>137</td>
<td>117000</td>
</tr>
<tr>
<td>6. Main Gear</td>
<td>1716</td>
<td>640</td>
<td>1098000</td>
<td>137</td>
<td>350000</td>
</tr>
<tr>
<td>6. Fixed eqpt.</td>
<td>7739</td>
<td>525</td>
<td>4063000</td>
<td>191</td>
<td>1480000</td>
</tr>
</tbody>
</table>

Empty Weight: \( W_e = 32935 \)

Operating Weight Empty: \( W_{OE} = 34068 \)

### Calculations

\[
\begin{align*}
\text{Take-off Weight: } W_{TD} &= 60683 \\
\text{Empty Weight: } W_e &= 32935 \\
\end{align*}
\]
Figure 3.3.3 Center of Gravity Excursion Diagram of the 75 Thin-Body Model
3.3.9.1 LONGITUDINAL STABILITY

It was originally envisioned that the horizontal tail of the 36 passenger airplane could be used on the 75 twin-body configuration. However, from stability and control calculations using the methods of chapter 11 in Reference 2, this was not possible. These calculations and the corresponding X-plot are located in section M.2 of Appendix M. From the X-plot, a 5% static margin would require a horizontal tail area of 190 ft\(^2\). To preserve commonality, two 102 ft\(^2\) horizontal tails from the 50 passenger airplane will be used.

3.3.9.2 LATERAL - DIRECTIONAL STABILITY

Using the method of chapter 11 in Reference 2, the engine out for the 75 passenger twin-body is critical for the vertical tail sizing (see Appendix M, section M.2). If the vertical tails designed for the 36 passenger airplane are used, a 27° rudder deflection is required to hold engine out. From the directional X-plot located in Appendix M, Figure M.3 a total vertical tail area of 260 ft\(^2\) (2x130) produces a \(C_n = 0.0018 \text{ deg}^{-1}\).

3.3.10 CLASS I DRAG POLARS

The component wetted areas were calculated using the method of chapter 12 in Reference 2, and are listed in Table 3.3.6. A skin friction coefficient of \(f = 0.0025\) is assumed. The increments in \(C_{D_o}\) due to flaps, gear, and compressibility are identical to those used in section 3.2.10. Table 3.3.7 lists the drag polars for take-off, cruise, and landing computed for this configuration. The engineering calculation for the drag polars are located in Appendix M, section M.3.

Assuming 40% of the take-off fuel weight has been used, the cruise lift coefficient is \(C_{L_{cr}} = 0.36\). The lift to drag ratio is then:

\[
(L/D)_{cr} = 15.3
\]

From Figure 3.21 Reference 1, assuming a \(c_f = 0.0025\).

\[
f = 14.5 \text{ ft}^2
\]

\[
C_{D_o} = f/S_{\text{ref}} = 14.5/722 = 0.0201
\]
**TABLE 3.3.5 STABILITY AND CONTROL RESULTS FOR THE 75 PASSENGER TWIN-BODY CONFIGURATION**

\[ S = 722 \text{ ft}^2 \]
\[ c = 7.5 \text{ ft} \]
\[ b = 104.5 \text{ ft} \]
\[ L.E. c = \text{F.S. 556} \]
\[ S_H = 200 \text{ ft}^2 \]
\[ S_V = 260 \text{ ft}^2 \]
\[ \Delta x_{AC_B} = -.39 \]
\[ \bar{x}_{AC_{WB}} = -.14 \]
\[ \bar{x}_{AC_A} = .404 \quad \text{F.S 592} \]
\[ \bar{x}_{AC_H} = 5.77 \]
\[ C_{L_{\alpha_W}} = 4.99 \text{ rad}^{-1} \]
\[ C_{L_{\alpha_H}} = 3.65 \text{ rad}^{-1} \]
\[ C_{L_{\alpha_V}} = 1.46 \text{ rad}^{-1} \]
\[ C_{\eta_B} = .102 \text{ rad}^{-1} \]
\[ \frac{d\bar{x}}{d\alpha} = .32 \]
\[ \bar{x}_{CG_{aft}} = .58 \quad \text{F.S. 608} \]
\[ x_V = 34.67 \text{ ft} \]

*All results calculated from References 5. and 6.*
### TABLE 3.3.6 WETTED AREA BREAKDOWN

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>WETTED AREA (ft^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing</td>
<td>1006</td>
</tr>
<tr>
<td>Horizontal Tail</td>
<td>420</td>
</tr>
<tr>
<td>Vertical Tail</td>
<td>534</td>
</tr>
<tr>
<td>Fuselage</td>
<td>3404</td>
</tr>
<tr>
<td>Engine Nacelles</td>
<td>248</td>
</tr>
<tr>
<td>Engine Pylons</td>
<td>480</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6092</strong></td>
</tr>
</tbody>
</table>

### TABLE 3.3.7 DRAG POLAR COMPARISON

<table>
<thead>
<tr>
<th>CONDITION</th>
<th>CLASS I</th>
<th>(L/D)_{max}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take-off</td>
<td>$C_D = 0.0351 + 0.0264 , C_L^2$</td>
<td>16.4</td>
</tr>
<tr>
<td>Cruise</td>
<td>$C_D = 0.0203 + 0.0248 , C_L^2$</td>
<td>22.3</td>
</tr>
<tr>
<td>Landing</td>
<td>$C_D = 0.1101 + 0.0264 , C_L^2$</td>
<td>9.3</td>
</tr>
</tbody>
</table>
3.4 PRESENTATION OF THE 50 PASSENGER CONFIGURATION

Figure 3.4.1 contains the Class I 3-view for the 50 passenger commuter. Table 3.4.1 contains the geometry of the configuration.

3.4.1 Initial Sizing of the 50 Passenger Commuter

From the methods in Reference 1, the weights and initial performance parameters were selected. These parameters depended on the mission specifications. These specifications and mission profile are shown in Table 3.4.2. The following assumptions were made for the airplane:

1) \( (L/D)_{cr} = 16 \)
2) \( C_p = 0.4 \text{ lbs/hp/hr} \)

The preliminary weight and performance sizing are done through the use of two computer programs developed at the University of Kansas. Appendix J, Section J.2 contains output from XEWTOG, the weight sizing program. Section J.3 contains output from XPRFRM, the performance program. The results of the initial weight and performance sizing are given in Table 3.4.3. A performance matching graph is displayed in Figure 3.4.2.

3.4.2 Fuselage and Cockpit Layout

The 50 passenger airplane has the same cockpit and fuselage cross section as the rest of the commuter family. The cockpit design and fuselage cross section are contained in Appendix A. The lengths of the fuselage and cabin are given in Table 3.4.1. The design methodology followed the steps in References 2 and 3.

3.4.3 Engine Selection

The commuter family will be powered by 2 advanced turboprop engines. The 50 passenger airplane requires the use of 6000 shp turboprops. Appendix B contains the engine data used.

3.4.4 Wing and Flap Design

Table 3.4.1 presents the geometry of the wing and flaps. Parameters such as leading edge sweep and thickness were dictated by the selection of a natural laminar flow (NLF) airfoil. Appendix C contains the airfoil cross section and airfoil parameters. Wing parameters were selected using the methods of Reference 2, Chapter 6.

The flaps were sized to a \( C_{L_{max}} = 3.0 \). This required the use of Fowler flaps. The sizing methods used are contained in Chapter 7 of Reference 2. The design calculations are given in Appendix J, Section J.4.
<table>
<thead>
<tr>
<th>Area</th>
<th>Aspect Ratio</th>
<th>Sweep Angle</th>
<th>Taper Ratio</th>
<th>Thickness Ratio</th>
<th>Overall</th>
<th>Wing</th>
<th>Overall</th>
<th>Wing</th>
<th>Overall</th>
<th>Wing</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing</td>
<td>592 ft²</td>
<td>12</td>
<td>5.0</td>
<td>0.40</td>
<td>0.10</td>
<td>170 ft²</td>
<td>22.6 ft</td>
<td>99.9 ft</td>
<td>104 ft</td>
<td>28.0 ft</td>
<td>84.3 ft</td>
</tr>
<tr>
<td>MGC</td>
<td>84.3 ft</td>
<td>13.1 deg</td>
<td>25.0 deg</td>
<td>0.13 root</td>
<td>0.10</td>
<td>15.4 ft</td>
<td>4.68 ft</td>
<td>90.3 ft</td>
<td>28.0 ft</td>
<td>7.60 ft</td>
<td></td>
</tr>
<tr>
<td>MGC</td>
<td>53.5 ft</td>
<td>0.40</td>
<td>0.50</td>
<td>0.13 root</td>
<td>0.12</td>
<td>11.4 ft</td>
<td>0.68 ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MGC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Airfoil</th>
<th>All airfoils are Natural Laminar Flow airfoils.</th>
<th>Overall</th>
<th>Overall</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dihedral Angle</td>
<td>12.0 deg</td>
<td>0.25</td>
<td>0.10 - 0.738</td>
<td></td>
</tr>
<tr>
<td>Incidence Angle</td>
<td>5.0 deg</td>
<td>0 deg</td>
<td>0 deg</td>
<td></td>
</tr>
<tr>
<td>Elevator chord ratio</td>
<td>0.36</td>
<td>0.738 - 1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rudder chord ratio</td>
<td>0.34</td>
<td>(full span)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flap chord ratio</td>
<td>0.25</td>
<td>0.10 - 0.738</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flap span ratio</td>
<td>0.10</td>
<td>(full span)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Length</th>
<th>Maximum Height</th>
<th>Maximum Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>94.6 ft</td>
<td>8.05 ft</td>
<td>8.05 ft</td>
</tr>
</tbody>
</table>
Table 3.4.2 Mission Specification for the 50 Passenger Advanced Technology Commuter Airplane

PAYLOAD: 50 passengers at 175 lbs each with 30 lbs of baggage per passenger, carry-on luggage capability is required

CREW: 2 pilots and 1 flight attendant at 175 lbs each with 30 lbs of baggage each

RANGE: 1100 nm with max payload with 25% fuel reserves

ALTITUDE: 30,000 ft at the design range

CRUISE SPEED: MACH = .70

CLIMB: climb rate of 3000 fpm

TAKE-OFF AND LANDING: 3500 ft balanced field length

POWERPLANTS: advanced turboprops

PRESSURIZATION: 5000 ft cabin at 30000 ft

CERTIFICATION BASE: FAR 25

MISSION PROFILE:

1. Take-off
2. Engine start-up
3. Climb
4. Cruise
5. Descent
6. Landing, taxi and shutdown
Table 3.4.3 Initial Sizing Parameters for the 50 Passenger Commuter

Weights:  
Take-off Weight  \( W_{TO} = 42,057 \text{ lbs} \)
Operating Weight Empty  \( W_{OE} = 23,963 \text{ lbs} \)
Payload Weight  \( W_{PL} = 10,250 \text{ lbs} \)
Crew Weight  \( W_{CREW} = 615 \text{ lbs} \)
Mission Fuel Weight  \( W_{F} = 6,913 \text{ lbs} \)

Wing Area  \( S = 592 \text{ ft}^2 \)
Aspect Ratio  \( A = 12.0 \)
Take-off Power  \( P_{TO} = 11,000 \text{ shp} \)

Required Lift Coefficients:
- Clean  \( C_{L_{max}} = 1.5 \)
- Take-off  \( C_{L_{max,TO}} = 2.0 \)
- Landing  \( C_{L_{max,L}} = 3.0 \)

Take-off Weight Sensitivities:
- \( \frac{\Delta W_{TO}}{\Delta c_p} = 39,784 \text{ lb/lb/hp/hr} \)
- \( \frac{\Delta W_{TO}}{\Delta n_p} = -18,722 \text{ lbs} \)
- \( \frac{\Delta W_{TO}}{\Delta (L/D)} = -994.6 \text{ lbs} \)
- \( \frac{\Delta W_{TO}}{\Delta R} = 15.1 \text{ lbs} \)
FIGURE 3.4.2
PERFORMANCE MATCHING OF
THE 50 PASSENGER MODEL

UNIVERSITY OF KANSAS
3.4.5 Design of the Empennage

Table 3.4.1 lists the empennage geometry for the 50 passenger airplane. Initially, the V-bar methods of Reference 2, Chapter 8, were used to size the empennage. These initial areas are listed below:

\[ S_H = 130 \text{ ft}^2 \]
\[ S_V = 130 \text{ ft}^2 \]

The empennage was redesigned from stability and control considerations which are discussed in section 3.4.9.

3.4.6 Control Surface Sizing

3.4.6.1 Lateral-Directional Controls

Table 3.4.1 presents the aileron geometry used. The methods used were that of Reference 2, Chapter 8.

3.4.6.2 Longitudinal Controls

The elevators were sized using methods in Chapter 8, Reference 2, and the geometry is summarized in Table 3.4.1.

3.4.7 Landing Gear Design

From Chapter 9, Reference 2, it was determined that a 30 X 9 inch tire could be used on every airplane of the commuter family. A preliminary retraction scheme for the main gear is shown in Appendix D. The gear placement was dictated by the weight and balance calculations shown in Section 3.4.8. Lateral tip-over and longitudinal gear retraction criteria given in Reference 1 were met. Appendix J, Section J.6 contains the lateral tip-over calculations.

3.4.8 Class I Weight and Balance Calculations

A preliminary weight and balance of the 50 passenger commuter was determined by using methods in Reference 2, Chapter 10. Component weights and center of gravity locations are contained in Table 3.4.4. A general arrangement drawing is provided by Figure 3.4.3. The weight-center of gravity excursion diagram is contained in Figure 3.4.4. The 50 passenger commuter has a 15 inch excursion range which corresponds to 0.17 \( C_w \).
**FIGURE 3.4.3** 50 PASSENGER GENERAL ARRANGEMENT
**Table 3.4.4 50 Passenger Commuter Class I Weight and Balance Calculation**

<table>
<thead>
<tr>
<th>No.</th>
<th>Component</th>
<th>Weight</th>
<th>$X_i$</th>
<th>$Z_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fuselage</td>
<td>5352</td>
<td>578</td>
<td>148</td>
</tr>
<tr>
<td>2</td>
<td>Wing</td>
<td>4873</td>
<td>687</td>
<td>127</td>
</tr>
<tr>
<td>3</td>
<td>Empennage</td>
<td>1219</td>
<td>1155</td>
<td>340</td>
</tr>
<tr>
<td>4</td>
<td>Engine</td>
<td>4552</td>
<td>855</td>
<td>229</td>
</tr>
<tr>
<td>5a</td>
<td>Nose Gear</td>
<td>373</td>
<td>220</td>
<td>74</td>
</tr>
<tr>
<td>5b</td>
<td>Main Gear</td>
<td>1497</td>
<td>720</td>
<td>64</td>
</tr>
<tr>
<td>6</td>
<td>Fixed Eqpt.</td>
<td>6177</td>
<td>598</td>
<td>148</td>
</tr>
<tr>
<td></td>
<td>Empty Weight</td>
<td>$W_E = 24043$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Trapped Fuel</td>
<td>210</td>
<td>745</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Crew</td>
<td>615</td>
<td>200</td>
<td></td>
</tr>
</tbody>
</table>

**Operating Weight Empty: $W_{DE} = 24868$**

9. Fuel 
$W_{DE} + W_F = 31807$

10. Passengers 
$W_{TO} = 42057$
$W_{TO} - W_F = 35118$
3.4.9 Stability and Control Analysis

A Class I stability and control analysis was performed using methods of Reference 2, Chapter 11. Table 3.4.5 lists the geometric quantities and stability derivatives necessary to size the empennage from stability and control considerations. Design calculations are located in Appendix J, Section J.7.

3.4.9.1 Longitudinal Stability

From methods in Chapter 11 of Reference 2, the horizontal tail was resized to incorporate a desired static margin of 5 percent. In order to achieve a common horizontal tail with the twin body 100 passenger design, it was necessary to size the 50 passenger horizontal tail to a static margin of 12.9 percent. Figure J.2 in Appendix J shows that a longitudinal tail area of 102 ft² is required. This area will be used in place of the original estimate of Section 3.4.5.
3.4.9.2 Lateral-Directional Stability

From methods in Chapter 11 of Reference 2, the vertical tail area required to hold engine-out flight was critical. The engines were put at a 5 degree cant to lessen the thrust moment arm about the airplane center of gravity. This allowed for a vertical tail area of 170 ft$^2$. Figure J.3 in Appendix J contains a directional x-plot for the airplane. It is observed that a 170 ft$^2$ vertical tail yields $c_n = 0.0958$ rad $^{-1}$.

3.4.10 Class I Drag Polars

From methods in Reference 2, Chapter 12, component wetted areas were calculated and listed in Table 3.4.6. The calculations for the wetted areas are given in Appendix J, Section J.8. From the total airplane wetted area and assuming a skin friction coefficient of $C_f = 0.0025$, $C_D = 0.0169$ was determined.

Table 3.4.7 contains the take-off, cruise and landing drag polars computed during the initial performance sizing. Changes to $C_D$ for take-off and landing drag polars are given in Appendix J, Section J.8.

Taking natural laminar flow into account should reduce the airplane $C_D$ by at least 10 percent. Assuming $C_{L_{CR}} = 0.3$, $(L/D)_{CR} = 14.1$. During initial take-off weight sizing $(L/D)_{CR}$ was assumed to be 16. It appears that an increase in take-off weight is necessary. From the take-off weight sensitivities given in Table 3.4.3, this change in $(L/D)$ results in an increase in take-off weight of 1889 lbs, or 4.5%. This amount change does not warrant resizing of the airplane, assuming that the 10% reduction in parasite drag is possible.
Table 3.4.5 Stability and Control Results for the 50 Passenger Commuter

\[ S = 592 \text{ ft}^2 \]
\[ c = 7.46 \text{ ft} \quad \text{L.E. } \bar{c}_w = \text{F.S. 642} \]
\[ b = 84.3 \text{ ft} \]
\[ S_H = 102 \text{ ft}^2 \]
\[ S_V = 170 \text{ ft}^2 \]
\[ \Delta \bar{x}_{ac_B} = -0.308 \]
\[ \bar{x}_{ac_{WB}} = -0.058 \]
\[ \bar{x}_{ac_A} = 0.465 \]
\[ \bar{x}_{ac_H} = 6.35 \]
\[ C_{L_{ac_{w}}} = 4.72 \text{ rad}^{-1} \]
\[ C_{L_{ac_{h}}} = 3.64 \text{ rad}^{-1} \]
\[ C_{L_{ac_{v}}} = 1.87 \text{ rad}^{-1} \]
\[ C_{p_{ac_B}} = 0.0958 \text{ rad}^{-1} \]
\[ \delta \alpha/\delta \alpha = 0.325 \]
\[ \bar{x}_{cg_{aft}} = 0.335 \quad \text{F.S. 672} \]
\[ X_V = 37.2 \text{ ft} \]
\[ X_H = 41.1 \text{ ft} \]

*All results calculated from References 5 and 6.*
Table 3.4.6 Wetted Area Breakdown

<table>
<thead>
<tr>
<th>Component</th>
<th>Wetted Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing</td>
<td>1059</td>
</tr>
<tr>
<td>Horizontal Tail</td>
<td>207</td>
</tr>
<tr>
<td>Vertical Tail</td>
<td>351</td>
</tr>
<tr>
<td>Fuselage</td>
<td>2115</td>
</tr>
<tr>
<td>Engine Nacelles</td>
<td>180</td>
</tr>
<tr>
<td>Engine Pylons</td>
<td>124</td>
</tr>
</tbody>
</table>

Total = 4036 ft²

\[ f = 12.1 \quad C_f = 0.0025 \quad C_D = 0.0169 \]

Table 3.4.7 Drag Polar Comparison

<table>
<thead>
<tr>
<th>Flight Condition</th>
<th>Initial</th>
<th>Class I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take-off</td>
<td>( C_D = 0.0634 + 0.0332C_L^2 )</td>
<td>( C_D = 0.0354 + 0.0332C_L^2 )</td>
</tr>
<tr>
<td>Cruise</td>
<td>( C_D = 0.0286 + 0.0312C_L^2 )</td>
<td>( C_D = 0.0206 + 0.0312C_L^2 )</td>
</tr>
<tr>
<td>Landing</td>
<td>( C_D = 0.0784 + 0.0332C_L^2 )</td>
<td>( C_D = 0.110 + 0.0332C_L^2 )</td>
</tr>
</tbody>
</table>

\( (L/D)_{\text{max}} \)

<table>
<thead>
<tr>
<th>Flight Condition</th>
<th>Initial</th>
<th>Class I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take-off</td>
<td>10.9</td>
<td>14.6</td>
</tr>
<tr>
<td>Cruise</td>
<td>16.8</td>
<td>19.7</td>
</tr>
<tr>
<td>Landing</td>
<td>9.81</td>
<td>8.28</td>
</tr>
</tbody>
</table>
3.5 PRESENTATION OF THE 100 PASSENGER TWIN FUSELAGE CONFIGURATION

Figure 3.5.1 contains the Class I 3-view from the 100 passenger twin body commuter. Table 3.5.1 contains the geometry of the configuration.

3.5.1 Initial Sizing of the 100 Passenger Twin Body

The 100 passenger twin body design is based on joining two optimally designed 50 passenger configurations, in hopes that:
1) high commonality in design and production between the 50 and 100 passenger configurations can be achieved,
2) the weight can be reduced from a conventional passenger configuration,
3) an innovative, futuristic design for the next century can be obtained.

The mission specifications and profile are provided in Table 3.5.2. The initial weight and performance sizing is based on the 50 passenger design and is listed in Table 3.5.3.

3.5.2 Fuselage and Cockpit Layouts

The 100 passenger twin fuselage design has the same cockpit and fuselage cross section as the rest of the commuter family with one exception: the right-hand side fuselage cockpit will be stripped of equipment and used as additional seating or for observation. The cockpit design and fuselage cross section are contained in Appendix A. The lengths of the fuselage and cabin are given in Table 3.5.1. The design methodology followed the steps in References 2 and 3.

3.5.2 Fuselage and Cockpit Layouts

The commuter family will be powered by two advanced turboprop engines. The 100 passenger twin body requires the use of the 13,500 shp turboprops. Appendix B contains the engine data used.

3.5.4 Wing and Flap Design

Table 3.5.1 presents the geometry of the wing and flaps. The wing planform and flaps are the same as that used on the 50 passenger airplane. A center wing joining the two fuselages and connected to the outboard wings was added. The center wing had the following characteristics:

Area, $S = 400 \text{ ft}^2$

Thickness Ratio, $t/c = 0.13$

Dihedral Angle and incidence angle, $\delta = i = 0 \text{ deg}$

The flaps were sized to a $C_{L_{\text{max}}}$ = 3.0. This required
### Table 3.5.1 Geometric Characteristics of the Twin Fuselage 100 Passenger Commuter Airplane

<table>
<thead>
<tr>
<th></th>
<th>Wing</th>
<th>Horizontal Tail</th>
<th>Vertical Tail</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Area</strong></td>
<td>923 ft²</td>
<td>354 ft²</td>
<td>140 ft²</td>
</tr>
<tr>
<td><strong>Span</strong></td>
<td>118 ft</td>
<td>55.8 ft</td>
<td>15.4 ft</td>
</tr>
<tr>
<td><strong>MGC</strong></td>
<td>8.33 ft</td>
<td>4.68</td>
<td>9.4 ft</td>
</tr>
<tr>
<td><strong>MGC L.E.: F.S.</strong></td>
<td>51.8 ft</td>
<td>99.9</td>
<td>91.7 ft</td>
</tr>
<tr>
<td><strong>Aspect Ratio</strong></td>
<td>15</td>
<td>5.0</td>
<td>1.7</td>
</tr>
<tr>
<td><strong>Sweep Angle</strong></td>
<td>15.0 deg</td>
<td>25.0 deg (L.E.)</td>
<td>40.0 deg (L.E.)</td>
</tr>
<tr>
<td><strong>Taper Ratio</strong></td>
<td>0.40</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td><strong>Thickness Ratio</strong></td>
<td>0.13 root</td>
<td>0.12 root</td>
<td>0.13 root</td>
</tr>
<tr>
<td></td>
<td>0.10 tip</td>
<td>0.10 tip</td>
<td>0.12 tip</td>
</tr>
<tr>
<td><strong>Airfoil:</strong></td>
<td>All airfoils are Natural Laminar Flow airfoils.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dihedral Angle</strong></td>
<td>7.0 deg</td>
<td>0 deg</td>
<td>0 deg</td>
</tr>
<tr>
<td><strong>Incidence Angle</strong></td>
<td>0 deg</td>
<td>0 deg</td>
<td>0 deg</td>
</tr>
<tr>
<td><strong>Aileron chord ratio</strong></td>
<td>0.25</td>
<td>Elevator chord ratio = 0.36</td>
<td></td>
</tr>
<tr>
<td><strong>Aileron span ratio</strong></td>
<td>0.750 - 0.97</td>
<td>(full span)</td>
<td>Rudder chord ratio = 0.34 (full span)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Flap chord ratio</strong></td>
<td>0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Flap span ratio</strong></td>
<td>0.10 - 0.738</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Fuselage</th>
<th>Cabin Interior</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length</strong></td>
<td>94.6 ft</td>
<td>45.0 ft</td>
<td>104 ft</td>
</tr>
<tr>
<td><strong>Maximum Height</strong></td>
<td>8.05 ft</td>
<td>6.30 ft</td>
<td>28.0 ft</td>
</tr>
<tr>
<td><strong>Maximum Width</strong></td>
<td>8.05 ft</td>
<td>7.60 ft</td>
<td>118 ft</td>
</tr>
</tbody>
</table>
Table 3.5.2 Mission Specification for the Twin Body 100 Passenger Advanced Technology Commuter Airplane

<table>
<thead>
<tr>
<th>Specification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAYLOAD:</td>
<td>100 passengers at 175 lbs each with 30 lbs of baggage per passenger, carry-on luggage capability is required</td>
</tr>
<tr>
<td>CREW:</td>
<td>2 pilots and 2 flight attendants at 175 lbs each with 30 lbs of baggage each</td>
</tr>
<tr>
<td>RANGE:</td>
<td>1500 nm with max payload with 25% fuel reserves</td>
</tr>
<tr>
<td>ALTITUDE:</td>
<td>30,000 ft at the design range</td>
</tr>
<tr>
<td>CRUISE SPEED:</td>
<td>MACH = .70</td>
</tr>
<tr>
<td>CLIMB:</td>
<td>Climb rate of 3000 fpm</td>
</tr>
<tr>
<td>TAKE-OFF AND LANDING:</td>
<td>3500 ft balanced field length</td>
</tr>
<tr>
<td>POWERPLANTS:</td>
<td>Advanced turboprops</td>
</tr>
<tr>
<td>PRESSURIZATION:</td>
<td>5000 ft cabin at 30000 ft</td>
</tr>
<tr>
<td>CERTIFICATION BASE:</td>
<td>FAR 25</td>
</tr>
</tbody>
</table>

**MISSION PROFILE:**

```
1 2 3 4 5 6 7
1. Take-off
2. Engine Start-up
3. Climb
4. Cruise
5. Descent
6. Landing, Taxi, and Shutdown
```
Table 3.5.3 Initial Sizing Parameters for the Twin Body 100 Passenger Commuter

Weights:
- Take-off Weight \( W_{TO} = 80,716 \) lbs
- Operating Weight Empty \( W_{OE} = 46,338 \) lbs
- Payload Weight \( W_{PL} = 20,500 \) lbs
- Crew Weight \( W_{CREW} = 615 \) lbs
- Mission Fuel Weight \( W_{F} = 13,878 \) lbs

Wing Area \( S = 923 \) ft\(^2\)

Aspect Ratio \( A = 15.0 \)

Take-off Power \( P_{TO} = 22,000 \) shp

Required Lift Coefficients:
- Clean \( C_{L_{\text{max}}} = 1.5 \)
- Take-off \( C_{L_{\text{max,TO}}} = 2.0 \)
- Landing \( C_{L_{\text{max,L}}} = 3.0 \)

Take-off Weight Sensitivities:

\[
\frac{\Delta W_{TO}}{\Delta p} = 39,784 \text{ lb/lb/hp/hr}
\]

\[
\frac{\Delta W_{TO}}{\Delta q} = -18,722 \text{ lbs}
\]

\[
\frac{\Delta W_{TO}}{\Delta (L/D)} = -994.6 \text{ lbs}
\]

\[
\frac{\Delta W_{TO}}{\Delta R} = 15.1 \text{ lbs}
\]

*assumed to be the same as the 50 passenger commuter
the use of Fowler flaps on the 50 passenger airplane. The center wing section has been designed to include full span flaps if needed.

Section 2.4.4 gives the details on the 50 passenger wing planform and flap design used for this configuration.

3.5.5 Design of the Empennage

Table 3.5.1 lists the empennage geometry for the 100 passenger twin body. Initially, the areas obtained by the V-bar method for the 50 passenger design (see Section 2.4.5) were doubled:

\[ S_V = 260 \text{ ft}^2 \]
\[ S_H = 260 \text{ ft}^2 \]

However, the empennage was redesigned from stability and control considerations of both the 100 passenger twin body and 50 passenger designs in Sections 2.4.9 and 3.5.9.

3.5.6 Control Surface Sizing

3.5.6.1 Lateral-Directional Controls

Table 3.5.1 presents the aileron geometry used. It is the same as designed for the 50 passenger design. Spoilers may be required in order to produce the extra roll-control required for a twin-fuselage design.

3.5.6.2 Longitudinal Controls

The elevators are the same as those for the 50 passenger design; the geometry is summarized in Table 3.5.1.

3.5.7 Landing Gear Design

From Chapter 9, Reference 2, it was determined that a 30 X 9 inch tire could be used on every airplane of the commuter family. A preliminary retraction scheme for the main gear is shown in Appendix D. The gear placement is the same as that for the 50 passenger airplane. The wheelbase for the 100 passenger twin body has been estimated to be 50 ft. From Airport Engineering by Ashford and Wright, the following conclusions are made:

1) This design can operate out of any airline airport.

2) This design will not be able to operate out of general aviation airports. General and basic transport general aviation airports have taxiway widths between 40 - 60 feet.
3.5.8 Class I Weight and Balance Calculations

A preliminary weight and balance of the 100 passenger twin body was determined by using methods in Reference 2, Chapter 10. Component weights and center of gravity locations are contained in Table 3.5.4. A general arrangement drawing is provided by Figure 2.4.2. The weight-center of gravity excursion diagram is contained in Figure 3.5.3. The 100 passenger twin body has a 22 inch excursion range which corresponds to 0.22 \( \frac{C}{W} \).

3.5.9 Stability and Control Analysis

A Class I stability and control analysis was performed using methods of Reference 2, Chapter 11. Table 3.5.5 lists all the geometric quantities and stability derivatives necessary to size the empennage from stability and control considerations. Appendix N (pages 8-22) provides the detailed calculations.

3.5.9.1 Longitudinal Stability

From methods in Chapter 11 of Reference 2, the horizontal tail was resized to best match that of the 50 passenger design while still maintaining an inherently stable static margin. Figure N.2 in Appendix N presents the longitudinal x-plot for the airplane. Since only 102 ft\(^2\) of horizontal tail area was required by the 50 passenger design, a horizontal boom has been proposed to connect the horizontal tail planforms (see Figure 3.5.1). This provides a horizontal tail area of 303 ft\(^2\) and allows the design of an inherently stable static margin of 7.5 percent.

3.5.9.2 Lateral-Directional Stability

From methods in Chapter 11 of Reference 2, the vertical tail area required to hold engine-out flight was not critical. Figure 3.5.5 provides the directional x-plot. The 100 passenger twin body only requires 230 ft\(^2\) of vertical tail area; however, the 50 passenger design required 170 ft\(^2\) due to engine-out requirements. The 100 passenger twin body will use two 140 ft\(^2\) vertical tails. From this the following results:

\[ S_v = 280 \text{ ft}^2 \]
\[ C_n = 0.098 \text{ rad}^{-1} \]
<table>
<thead>
<tr>
<th>No.</th>
<th>Component</th>
<th>Weight (lbs)</th>
<th>X\textsubscript{i} (in)</th>
<th>Z\textsubscript{i} (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Fuselage</td>
<td>10704</td>
<td>578</td>
<td>148</td>
</tr>
<tr>
<td>2.</td>
<td>Wing</td>
<td>7597</td>
<td>672</td>
<td>127</td>
</tr>
<tr>
<td>3.</td>
<td>Empennage</td>
<td>2438</td>
<td>1204</td>
<td>340</td>
</tr>
<tr>
<td>4.</td>
<td>Engine</td>
<td>8470</td>
<td>870</td>
<td>222</td>
</tr>
<tr>
<td>5a.</td>
<td>Nose Gear</td>
<td>746</td>
<td>220</td>
<td>74</td>
</tr>
<tr>
<td>5b.</td>
<td>Main Gear</td>
<td>2994</td>
<td>720</td>
<td>64</td>
</tr>
<tr>
<td>6.</td>
<td>Fixed Eqpt.</td>
<td>12354</td>
<td>578</td>
<td>148</td>
</tr>
</tbody>
</table>

Empty Weight \( W_E = 45303 \)

| 7.  | Trapped Fuel and Oil | 420 | 745 | 178 |
| 8.  | Crew               | 615 | 200 | 120 |

Operating Weight Empty: \( W_{OE} = 46338 \)

| 9.  | Fuel             | 13878 | 672 | 127 |
|     | \( W_{OE} + W_F = 60216 \) |  |  |  |
| 10. | Passengers      | 20500 | 630 | 148 |

Take-off Weight \( W_{TO} = 80716 \)

\( W_{TO} - W_F = 66838 \)
Table 3.5.5 Stability and Control Results for the Twin Body 100 Passenger Commuter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S$</td>
<td>923 ft$^2$</td>
</tr>
<tr>
<td>$\bar{c}$</td>
<td>8.33 ft</td>
</tr>
<tr>
<td>$\bar{c}_w$</td>
<td>F.S. 622</td>
</tr>
<tr>
<td>$b$</td>
<td>118 ft</td>
</tr>
<tr>
<td>$S_H$</td>
<td>354 ft$^2$</td>
</tr>
<tr>
<td>$S_V$</td>
<td>280 ft$^2$</td>
</tr>
<tr>
<td>$\Delta X_{ac_B}$</td>
<td>-0.390</td>
</tr>
<tr>
<td>$\bar{X}<em>{ac</em>{WB}}$</td>
<td>-0.140</td>
</tr>
<tr>
<td>$\bar{X}_{ac_A}$</td>
<td>0.622 F.S. 684</td>
</tr>
<tr>
<td>$\bar{X}_{ac_H}$</td>
<td>6.50</td>
</tr>
<tr>
<td>$\bar{X}<em>{ac</em>{He}}$</td>
<td>1.71</td>
</tr>
<tr>
<td>$C_{L_{\alpha_W}}$</td>
<td>5.20 rad$^{-1}$</td>
</tr>
<tr>
<td>$C_{L_{\alpha_H}}$</td>
<td>3.69 rad$^{-1}$</td>
</tr>
<tr>
<td>$C_{L_{\alpha_{He}}}$</td>
<td>4.13 rad$^{-1}$</td>
</tr>
<tr>
<td>$C_{L_{\alpha_V}}$</td>
<td>2.14 rad$^{-1}$</td>
</tr>
<tr>
<td>$C_{n_B}$</td>
<td>0.098 rad$^{-1}$</td>
</tr>
<tr>
<td>$d\beta/d\alpha$</td>
<td>0.344</td>
</tr>
<tr>
<td>$\bar{X}<em>{c</em>{gaft}}$</td>
<td>0.580 F.S. 680</td>
</tr>
<tr>
<td>$X_V$</td>
<td>41.3 ft</td>
</tr>
</tbody>
</table>

*All results calculated from References 5 and 6.*
3.5.10 Class I Drag Polars

From methods in Reference 2, Chapter 12, component wetted areas were calculated and listed in Table 3.5.6. The calculations for the wetted areas are given in Appendix N, Section N.8. From the total airplane wetted area and assuming a skin friction coefficient of $c_f = 0.0025$, $C_{D_o} = 0.0184$ was determined. Table 3.5.7 contains take-off, cruise, and landing drag polars which result. Changes to $C_{D_o}$ for take-off and landing drag polars are given Appendix N, Section N.8.

Assuming $C_{L_{CR}} = 0.3$, $(L/D)_{CR} = 14.4$. This decrease in $(L/D)_{CR}$ from that of the 50 passenger design was anticipated due to the large increase in wetted area in key places: fuselage, engine pylons, and center wing surfaces. However, if 10 percent laminar flow is assumed as in the 50 passenger design, $(L/D)_{CR} = 15.8$. This corresponds to the design goal of $(L/D)_{CR} = 16$. Detailed calculations are provided in Appendix N (pages 23-27).
### Table 3.5.6 Wetted Area Breakdown

<table>
<thead>
<tr>
<th>Component</th>
<th>Wetted Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing</td>
<td>1042</td>
</tr>
<tr>
<td>Horizontal Tail</td>
<td>625</td>
</tr>
<tr>
<td>Vertical Tail</td>
<td>567</td>
</tr>
<tr>
<td>Fuselage</td>
<td>4270</td>
</tr>
<tr>
<td>Engine Nacelles</td>
<td>393</td>
</tr>
<tr>
<td>Pylons</td>
<td>315</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7212 ft²</strong></td>
</tr>
</tbody>
</table>

\[ f = 17.0 \quad C_f = 0.0025 \quad C_D = 0.0184 \]

### Table 3.5.7 Twin Body Drag Polars

<table>
<thead>
<tr>
<th>Flight Condition</th>
<th>Class I Drag Polar</th>
<th>((L/D)_{max})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take-off</td>
<td>(C_D = 0.0334 + 0.0265C_L)</td>
<td>16.8</td>
</tr>
<tr>
<td>Cruise</td>
<td>(C_D = 0.0186 + 0.0250C_L)</td>
<td>23.2</td>
</tr>
<tr>
<td>Landing</td>
<td>(C_D = 0.1084 + 0.0265C_L)</td>
<td>9.32</td>
</tr>
</tbody>
</table>
3.6 PRELIMINARY DESIGN OF THE 75 PASSENGER BASELINE CONFIGURATION

The purpose of this chapter is to present the preliminary design of the 75 passenger regional transport. Figure 3.6.1 shows the Class I three-view of the NASA-100. Table 3.6.1 presents the geometric parameters for the NASA-100.

3.6.1 INITIAL WEIGHT AND PERFORMANCE SIZING FOR THE 75 PASSENGER BASELINE CONFIGURATION

3.6.1.1 INITIAL WEIGHT SIZING

Initial weight sizing was conducted using a method in Reference 1. The following assumptions were made for the airplane:

1) \((L/D)_{cr} = 16\)

2) \(c_p = 0.4 \text{ lbs/hp/hr}\)

The above assumptions and the mission specifications, given in Table 3.6.2, yielded the airplane weights and sensitivities in Table 3.6.3. Appendix K, section K.2, contains output from XEWTOG, a computerized weight sizing method developed at the University of Kansas.

3.6.1.2 INITIAL PERFORMANCE SIZING

XPRFRM, a computer program developed at the University of Kansas, was used to determine the required take-off power, \(P_{TO}\) and wing area, \(S\), that meet the performance criteria given in Table 3.6.2. XPRFRM follows the method of Reference 1. Maximum lift coefficients and wing aspect ratio are also determined. Figure 3.6.2 shows the required power loading, wing loading combinations that satisfy the performance criteria. From Figure 3.6.2, it is determined that cruise speed and landing field length requirements are critical for this airplane. The results of the performance sizing effort are listed in Table 3.6.2. Appendix K, section K.3, details the computer output of XPRFRM.

3.6.2 FUSELAGE AND COCKPIT LAYOUTS

The fuselage and cockpit layouts were determined using the methods of Chapter 4 in Ref. 2 and Chapter 2 in Ref. 3.

The 75 passenger transport has the same flight deck layout and fuselage cross-section as the rest of the
### TABLE 3.6.1--TABLE OF GEOMETRY FOR THE 75 PASSENGER COMMUTER.

<table>
<thead>
<tr>
<th></th>
<th>Wing</th>
<th>Horizontal Tail</th>
<th>Vertical Tail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area, S (ft²)</td>
<td>1178</td>
<td>134</td>
<td>363</td>
</tr>
<tr>
<td>Span, b (ft)</td>
<td>119</td>
<td>26.7</td>
<td>22.5</td>
</tr>
<tr>
<td>MGC, c (ft)</td>
<td>10.5</td>
<td>5.4</td>
<td>16.4</td>
</tr>
<tr>
<td>MGC LE: F.S.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspect ratio, A</td>
<td>12</td>
<td>5.3</td>
<td>1.4</td>
</tr>
<tr>
<td>Sweep angle, (deg)</td>
<td>13 (c/4)</td>
<td>22 (c/4)</td>
<td>42 (c/4)</td>
</tr>
<tr>
<td>Taper ratio,</td>
<td>0.4</td>
<td>0.35</td>
<td>0.6</td>
</tr>
<tr>
<td>Thickness ratio, t/c</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>Airfoil</td>
<td>NLF</td>
<td>NLF</td>
<td>NLF</td>
</tr>
<tr>
<td>Dihedral, (deg)</td>
<td>7</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>Incidence, i (deg)</td>
<td>0</td>
<td>Variable</td>
<td>0</td>
</tr>
<tr>
<td>Spoiler:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chord ratio</td>
<td>0.14</td>
<td>Elevator:</td>
<td>Rudder:</td>
</tr>
<tr>
<td>Span location</td>
<td>0.43/0.70</td>
<td>0.39/0.45</td>
<td>0.35</td>
</tr>
<tr>
<td>Flaps:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chord ratio</td>
<td>0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Span ratio</td>
<td>0.07/1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuselage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length, l (ft)</td>
<td>108</td>
<td>67.5</td>
<td>121</td>
</tr>
<tr>
<td>Maximum width, (ft)</td>
<td>8.05</td>
<td>7.60</td>
<td>119</td>
</tr>
<tr>
<td>Maximum height, (ft)</td>
<td>14.0</td>
<td>6.30</td>
<td>36.9</td>
</tr>
</tbody>
</table>

**ORIGINAL PAGE IS OF POOR QUALITY**
| PAYLOAD: | 75 passengers at 175 lbs each with 30 lbs of baggage per passenger, carry-on luggage capability is required |
| CREW: | 2 pilots and 2 flight attendants at 175 lbs each with 30 lbs of baggage each |
| RANGE: | 1500 nm with max payload with 25% fuel reserves |
| ALTITUDE: | 30,000 ft at the design range |
| CRUISE SPEED: | MACH = 0.70 |
| CLIMB: | climb rate of 3000 fpm |
| TAKE-OFF AND LANDING: | 3500 ft balanced field length |
| POWERPLANTS: | advanced turboprops |
| PRESSURIZATION: | 5000 ft cabin at 30,000 ft |
| CERTIFICATION BASE: | FAR 25 |

**MISSION PROFILE:**

![mission profile diagram]
<table>
<thead>
<tr>
<th>TABLE 3.6.3--INITIAL SIZING PARAMETERS FOR THE 75-PASSENGER COMMUTER.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weights: Take-off weight - ( W_{TO} = 82,491 ) lbs.</td>
</tr>
<tr>
<td>Empty weight - ( W_E = 48,175 ) lbs.</td>
</tr>
<tr>
<td>Payload weight - ( W_{PL} = 15,375 ) lbs.</td>
</tr>
<tr>
<td>Mission fuel weight - ( W_F = 17,898 ) lbs.</td>
</tr>
<tr>
<td>Crew weight - ( W_{CREW} = 820 ) lbs.</td>
</tr>
<tr>
<td>Wing area: ( S = 1178 ) ft(^2).</td>
</tr>
<tr>
<td>Wing Aspect ratio: ( A = 12 ).</td>
</tr>
<tr>
<td>Take-off power: ( P_{TO} = 19,640 ) lbs.</td>
</tr>
<tr>
<td>Required lift coefficients: Clean, ( C_{L,\max} = 1.40 ).</td>
</tr>
<tr>
<td>Take-off, ( C_{L,\max} = 1.80 ).</td>
</tr>
<tr>
<td>Landing, ( C_{L,\max} = 3.00 ).</td>
</tr>
<tr>
<td>Take-off weight sensitivities:</td>
</tr>
<tr>
<td>( SFC ) - ( \frac{\Delta W_{TO}}{\Delta c_p} = 143,189 ) lb/lb/lb/hr</td>
</tr>
<tr>
<td>Propeller efficiency- ( \frac{\Delta W_{TO}}{\Delta n_p} = -67,383 ) lbs</td>
</tr>
<tr>
<td>Lift-to-drag ratio - ( \frac{\Delta W_{TO}}{\Delta (L/D)} = -3,579 ) lbs</td>
</tr>
<tr>
<td>Range - ( \frac{\Delta W_{TO}}{\Delta R} = 38.2 ) lb/nm</td>
</tr>
</tbody>
</table>
commuter family. Appendix A contains the fuselage cross-section and cockpit layout design. Table 3.6.1 gives the main dimensions of the fuselage.

3.6.3 ENGINE SELECTION

The engines were selected using the methods of Chapter 5 in Ref. 2. Two advanced turbo-props were chosen at a power rating of 13,500 shp per engine. The engine data is given in Appendix B.

3.6.4 WING AND FLAP DESIGN

Table 3.6.1 presents the geometry of the wing and flaps. Parameters such as leading edge sweep and wing thickness were decided by the selection of an NLF airfoil. Appendix C contains the airfoil cross section and airfoil parameters. Wing parameters were selected using the method of Chapter 6 in Ref. 2.

The flaps were sized to a $C_{L_{max}} = 3.0$. This required the use of Fowler flaps. The sizing methods used are contained in Chapter 7 of Ref. 2. The design calculations are in Appendix K, section K.4.

3.6.5 DESIGN OF THE EMPENNAGE

Table 3.6.1 shows the empennage for the 75 passenger airplane. Initially, the V-bar method in chapter 8 of Ref. 2 was used to size the empennage. The design calculations are in Appendix K, section K.5. The initial tail areas that resulted are listed below:

\[ S_H = 242 \text{ ft}^2 \]

\[ S_V = 363 \text{ ft}^2 \]

After the stability and control calculations of Section 3.6.9 were completed, the empennage was resized. These considerations are discussed in section 3.6.9.

3.6.6 CONTROL SURFACE SIZING

3.6.6.1 LATERAL - DIRECTIONAL CONTROLS

Since full span flaps were required for landing, spoilers were used in place of ailerons. The spoiler geometry is contained in Table 3.6.1. This geometry was determined from Chapter 8 of Ref. 2.
The rudder was also sized with the method of Chapter 8 in Ref. 2. The rudder geometry is given in Table 3.6.1.

3.6.6.2 LONGITUDINAL CONTROLS

The elevators were sized using the methods in Chapter 8 of Ref. 2. Geometric parameters for the elevators are presented in Table 3.6.1.

3.6.7 LANDING GEAR DESIGN

From Chapter 9 of Ref. 2, it was determined that a 30" x 9" tire could be utilized for the nose and main landing gear on every airplane of the commuter family. A preliminary retraction scheme for the main gear is shown in Appendix D. The gear placement was dictated by weight and balance calculations shown in section 3.6.8. Both the longitudinal and the lateral tip-over criterion were satisfied. Appendix K, section K.6, contains the lateral tip-over calculations.

3.6.8 CLASS I WEIGHT AND BALANCE CALCULATIONS

The weight and balance for the NASA-100 was done after calculating the Class I component weights for the airplane. The component weights were calculated using average weight fractions for the commuter category of airplanes. Appendix F contains the Class I weight fractions for the commuter family. The preliminary weight and balance was then determined using the methods of Chapter 10 in Ref. 2.

The weight breakdown and the center of gravity locations are presented in Table 3.6.4. The center of gravity travel was contained to a range of 30 inches. This travel is 0.21 \( \bar{C}_w \). Figure 3.6.4 diagrams the center of gravity excursion for the 75 passenger airplane. Fig. 3.6.4 locates the component cg's on the airplane three-view.

3.6.9 STABILITY AND CONTROL RESULTS

Chapter 11 of Ref. 2 outlines the methods used in the preliminary stability and control calculations. Ref. 5 and Ref. 6 were used as supplements for these calculations. Table 3.6.5 contains geometric quantities and stability derivatives necessary to size the empennage for inherent stability. Design calculations are located in Appendix K, section K.7.

3.6.9.1 LONGITUDINAL STABILITY

From methods in Chapter 11 of Ref. 2, the horizontal tail was resized to incorporate a desired static margin of 5%.
<table>
<thead>
<tr>
<th>No.</th>
<th>Type of Component</th>
<th>( W_i )</th>
<th>( x_i )</th>
<th>( W_i \cdot x_i )</th>
<th>( z_i )</th>
<th>( W_i \cdot z_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Fuselage</td>
<td>10,311</td>
<td>6.2</td>
<td>6.372 \times 10^4</td>
<td>1.25</td>
<td>1.114 \times 10^4</td>
</tr>
<tr>
<td>2.</td>
<td>Wing</td>
<td>9,404</td>
<td>8.7</td>
<td>8.182 \times 10^4</td>
<td>1.06</td>
<td>0.858 \times 10^4</td>
</tr>
<tr>
<td>3.</td>
<td>Empennage</td>
<td>2,392</td>
<td>13.8</td>
<td>3.300 \times 10^4</td>
<td>3.77</td>
<td>0.883 \times 10^4</td>
</tr>
<tr>
<td>4.</td>
<td>Engine</td>
<td>10,288</td>
<td>13.6</td>
<td>1.399 \times 10^5</td>
<td>2.17</td>
<td>2.233 \times 10^4</td>
</tr>
<tr>
<td>5.</td>
<td>Landing gear</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>a. Nose gear</td>
<td>709</td>
<td>2.5</td>
<td>0.172 \times 10^4</td>
<td>0.58</td>
<td>0.031 \times 10^4</td>
</tr>
<tr>
<td></td>
<td>b. Main gear</td>
<td>2,837</td>
<td>8.8</td>
<td>2.497 \times 10^4</td>
<td>0.58</td>
<td>0.165 \times 10^4</td>
</tr>
<tr>
<td>6.</td>
<td>Fixed eqpt.</td>
<td>12,044</td>
<td>4.9</td>
<td>5.883 \times 10^4</td>
<td>1.25</td>
<td>1.505 \times 10^4</td>
</tr>
</tbody>
</table>

Empty weight: \( W_E = 47,986 \) lbs
\[
\begin{align*}
  x_{\text{cgWe}} &= 846 \text{ in} \\
  z_{\text{cgWe}} &= 136 \text{ in}
\end{align*}
\]

7. Trapped fuel and oil | 411 | 10.6 | 4.377 \times 10^3 | 1.49 | 0.613 \times 10^3 |

8. Crew | 820 | 2.5 | 1.976 \times 10^3 | 1.26 | 0.513 \times 10^3 |

Operating empty weight: \( W_{OE} = 49,218 \) lbs
\[
\begin{align*}
  x_{\text{cgWoe}} &= 838 \text{ in} \\
  z_{\text{cgWoe}} &= 136 \text{ in}
\end{align*}
\]

9. Fuel | 17,898 | 8.6 | 1.546 \times 10^5 | 1.04 | 1.861 \times 10^4 |

10. Passengers | 15,375 | 7.5 | 1.159 \times 10^5 | 1.25 | 1.922 \times 10^4 |

Take-off weight: \( W_{TO} = 82,491 \) lbs
\[
\begin{align*}
  x_{\text{cgWto}} &= 818 \text{ in} \\
  z_{\text{cgWto}} &= 127 \text{ in}
\end{align*}
\]
TABLE 3.6.5--STABILITY AND CONTROL RESULTS FOR THE 75 PASSENGER COMMUTER.

S = 1178 ft^2; \bar{c} = 10.5 ft; b = 119 ft.

\[ \Delta x_{ac_B} = -0.13 \]
\[ x_{ac_{WB}} = 0.12 \]
\[ x_{ac_A} = 0.428 \]
\[ x_{ac_H} = 4.87 \]
\[ C_{L_{ac_{WB}}} = 4.71 \text{ rad}^{-1} \]
\[ C_{L_{ac_{H}}} = 3.51 \text{ rad}^{-1} \]
\[ C_{L_{ac_V}} = 1.43 \text{ rad}^{-1} \]
\[ C_{n_{B}} = 0.0573 \text{ rad}^{-1} \]
\[ \frac{\delta c}{\delta \alpha} = 0.185 \]
\[ x_{c_B} = 0.29 \]
\[ x_{V} = 36.7 \text{ ft.} \]
Appendix K, Figure K.2 presents the longitudinal x-plot for the 75 passenger airplane. From this plot, it is seen that a tail area of 134 ft$^2$ is required.

3.6.9.2 LATERAL - DIRECTIONAL STABILITY

From the method of Chapter 11 in Ref. 2, the vertical tail area required to hold engine-out flight was found to be critical. The engines were set at a five degree cant to lessen the thrust moment arm about the cg. The directional x-plot is given in Appendix K, Figure K.3. From this plot, it can be seen that a vertical tail area of 363 ft$^2$ yields a $C_{n_B} = 0.0010$ deg$^{-1}$.

3.6.10 CLASS I DRAG POLARS

The Class I drag polars were calculated from the procedure of Chapter 12 in Ref. 2. The wetted areas of the airplane components were calculated as presented in Table 3.6.6 and Appendix K, section K.8. From the total airplane wetted area and assuming a skin friction coefficient of 0.0025, $C_{D_0}$ for the airplane was calculated.

Table 3.6.7 contains the take-off, cruise, and landing drag polars computed during the initial performance sizing. These drag polars are compared to the drag polars computed from wetted area considerations. These Class I drag polars more accurately represent the airplane. Changes to $C_{D_0}$ for take-off and landing conditions are given in Appendix K, section K.8.

The clean zero-lift drag coefficient at low speed was determined as:

$$C_{D_0} = 0.0124$$

The drag polars for take-off, landing, and cruise were then calculated as shown in Appendix K.

Assuming a $C_{L_{cr}} = 0.3$, the final drag polars yield:

$$(L/D)_{cr} = 12.4$$

During initial take-off weight sizing, $(L/D)_{cr}$ was assumed to be 16.
TABLE 3.6.6—WETTED AREA BREAKDOWN.

<table>
<thead>
<tr>
<th>Component</th>
<th>$S_{\text{wet}}$ (ft$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Wing</td>
<td>2212</td>
</tr>
<tr>
<td>2. Horizontal tail</td>
<td>277</td>
</tr>
<tr>
<td>3. Vertical tail</td>
<td>750</td>
</tr>
<tr>
<td>4. Fuselage</td>
<td>2463</td>
</tr>
<tr>
<td>5. Engines</td>
<td>1248</td>
</tr>
<tr>
<td>6. Engine pylons</td>
<td>25</td>
</tr>
<tr>
<td>Total</td>
<td>5975</td>
</tr>
</tbody>
</table>

From Figure 3.2.1 of Reference 1, assuming $c_f = 0.0025$:

$$f = 14.6 \text{ ft}^2$$

$$C_{D_0} = \frac{f}{S_{\text{REF}}} = \frac{14.6}{1178} = 0.0124$$

TABLE 3.6.7—DRAG POLAR COMPARISON.

Preliminary Results Drag Polar \((L/D)_{\text{max}}\)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>(L/D)$_{\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Clean</td>
<td>$0.0208 + 0.0312C_L^2$</td>
<td>19.6</td>
</tr>
<tr>
<td>2. Take-off, gear down</td>
<td>$0.0358 + 0.0332C_L^2$</td>
<td>14.5</td>
</tr>
<tr>
<td>3. Landing, gear down</td>
<td>$0.0958 + 0.0332C_L^2$</td>
<td>8.9</td>
</tr>
<tr>
<td></td>
<td>((L/D)_{\text{cruise}}) at $C_L = 0.3$ = 12.7</td>
<td></td>
</tr>
</tbody>
</table>

Class I Results

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>(L/D)$_{\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Clean</td>
<td>$0.0214 + 0.0312C_L^2$</td>
<td>19.4</td>
</tr>
<tr>
<td>2. Take-off, gear down</td>
<td>$0.0474 + 0.0332C_L^2$</td>
<td>12.6</td>
</tr>
<tr>
<td>3. Landing, gear down</td>
<td>$0.1074 + 0.0332C_L^2$</td>
<td>8.4</td>
</tr>
<tr>
<td></td>
<td>((L/D)_{\text{cruise}}) at $C_L = 0.3$ = 12.4</td>
<td></td>
</tr>
</tbody>
</table>
The sensitivities to take-off weight given in Table 3.6.3 show that:

\[ \frac{\delta W_{TO}}{\delta (L/D)} = -3,579 \text{ lbs} \]

For the baseline configuration, this translates into:

\[ (L/D)_{cr} = 12.4 - 16 = -3.6 \]

\[ W_{TO} = \Delta (L/D)_{cr} \frac{\delta W_{TO}}{\delta (L/D)} = 12,884 \text{ lbs.} \]

Since the take-off weight is 82,491 lbs, the decrease in lift-to-drag ratio causes a 16\% increase in take-off weight. According to Ref. 2, this percentage change in take-off weight indicates that the airplane needs to be resized with the initial weight sizing methods of Ref. 1.
3.7 PRELIMINARY DESIGN OF THE 100 PASSENGER BASELINE CONFIGURATION

The purpose of this chapter is to present the preliminary design of the NASA-100 regional transport. Figure 3.7.1 shows the Class I three-view of the NASA-100. Table 3.7.1 presents the geometric parameters for the NASA-100.

3.7.1 INITIAL WEIGHT AND PERFORMANCE SIZING FOR THE 100 PASSENGER BASELINE CONFIGURATION

3.7.1.1 INITIAL WEIGHT SIZING

Initial weight sizing was conducted using a method in Reference 1. The following assumptions were made for the airplane:

1) \((L/D)_{cr} = 16\)

2) \(c_p = 0.4 \text{ lbs/hp/hr}\)

The above assumptions and the mission specifications, given in Table 3.7.2, yielded the airplane weights and sensitivities in Table 3.7.3. Appendix L, section L.2, contains output from XEWTOG, a computerized weight sizing method developed at the University of Kansas.

3.7.1.2 INITIAL PERFORMANCE SIZING

XPRFRM, a computer program developed at the University of Kansas, was used to determine the required take-off power, \(P_{TO}\), and wing area, \(S\), that meet the performance criteria given in Table 3.7.2. XPRFRM follows the method of Reference 1. Maximum lift coefficients and wing aspect ratio are also determined. Figure 3.7.2 shows the required power loading, wing loading combinations that satisfy the performance criteria. From Figure 3.7.2, it is determined that cruise speed and landing field length requirements are critical for this airplane. The results of the performance sizing effort are listed in Table 3.7.2. Appendix L, section L.3, details the computer output of XPRFRM.

3.7.2 FUSELAGE AND COCKPIT LAYOUTS

The fuselage and cockpit layouts were determined using the methods of Chapter 4 in Ref. 2 and Chapter 2 in Ref. 3.

The 100 passenger transport has the same flight deck layout and fuselage cross-section as the rest of the
<table>
<thead>
<tr>
<th></th>
<th>Wing</th>
<th>Horizontal Tail</th>
<th>Vertical Tail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area, S (ft²)</td>
<td>1604</td>
<td>155</td>
<td>300</td>
</tr>
<tr>
<td>Span, b (ft)</td>
<td>139</td>
<td>28.7</td>
<td>20.6</td>
</tr>
<tr>
<td>MGC, c (ft)</td>
<td>11.6</td>
<td>5.4</td>
<td>15.0</td>
</tr>
<tr>
<td>MGC LE: F.S.</td>
<td>925</td>
<td>1675</td>
<td>1530</td>
</tr>
<tr>
<td>Aspect ratio, A</td>
<td>12</td>
<td>5.3</td>
<td>1.4</td>
</tr>
<tr>
<td>Sweep angle, (deg)</td>
<td>15 (LE)</td>
<td>22 (c/4)</td>
<td>42 (c/4)</td>
</tr>
<tr>
<td>Taper ratio,</td>
<td>0.4</td>
<td>0.35</td>
<td>0.6</td>
</tr>
<tr>
<td>Thickness ratio, t/c</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>Airfoil</td>
<td>NLF</td>
<td>NLF</td>
<td>NLF</td>
</tr>
<tr>
<td>Dihedral, (deg)</td>
<td>7</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>Incidence, i (deg)</td>
<td>0</td>
<td>Variable</td>
<td>0</td>
</tr>
<tr>
<td>Spoiler:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chord ratio</td>
<td>0.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Span location</td>
<td>0.4/0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hinge line</td>
<td>0.70c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aileron:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chord ratio</td>
<td>0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Span ratio</td>
<td>0.76/1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flaps:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chord ratio</td>
<td>0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Span ratio</td>
<td>0.06/0.76</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fuselage</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length, l (ft)</td>
<td>126</td>
</tr>
<tr>
<td>Maximum width, (ft)</td>
<td>8.05</td>
</tr>
<tr>
<td>Maximum height, (ft)</td>
<td>8.05</td>
</tr>
</tbody>
</table>
TABLE 3.7.2--MISSION SPECIFICATION FOR A 100 PASSENGER ADVANCED TECHNOLOGY COMMUTER AIRPLANE

PAYLOAD: 100 passengers at 175 lbs each with 30 lbs of baggage per passenger, carry-on luggage capability is required

CREW: 2 pilots and 2 flight attendants at 175 lbs each with 30 lbs of baggage each

RANGE: 1500 nm with max payload with 25% fuel reserves

ALTITUDE: 30,000 ft at the design range

CRUISE SPEED: MACH = .70

CLIMB: climb rate of 3000 fpm

TAKE-OFF AND LANDING: 3500 ft balanced field length

POWERPLANTS: advanced turboprops

PRESSURIZATION: 5000 ft cabin at 30,000 ft

CERTIFICATION BASE: FAR 25

MISSION PROFILE:
TABLE 3.7.3--INITIAL SIZING PARAMETERS FOR THE 100 PASSENGER COMMUTER.

Weights: Take-off weight - \( W_{TO} = 112,288 \text{ lbs.} \)
Operating weight empty - \( W_{DWE} = 67,422 \text{ lbs.} \)
Empty weight - \( W_E = 66,041 \text{ lbs.} \)
Payload weight - \( W_{PL} = 20,500 \text{ lbs.} \)
Mission fuel weight - \( W_F = 24,366 \text{ lbs.} \)
Crew weight - \( W_{CREW} = 820 \text{ lbs.} \)

Wing area: \( S = 1604 \text{ ft}^2. \)
Wing Aspect ratio: \( A = 12. \)
Take-off power: \( P_{TO} = 26,750 \text{ lbs.} \)

Required lift coefficients:
Clean, \( C_{L_{max}} = 1.32. \)
Take-off, \( C_{L_{max}} = 1.80. \)
Landing, \( C_{L_{max}} = 3.00. \)

Take-off weight sensitivities:
Payload weight - \( \frac{\Delta W_{TO}}{\Delta W_{PL}} = 5.9 \)
Empty weight - \( \frac{\Delta W_{TO}}{\Delta W_E} = 1.6 \)
SFC - \( \frac{\Delta W_{TO}}{\Delta c_p} = 202,659 \text{ lb/lb/lb/hr} \)
Propeller efficiency - \( \frac{\Delta W_{TO}}{\Delta \eta_p} = -95,369 \text{ lbs} \)
Lift-to-drag ratio - \( \frac{\Delta W_{TO}}{\Delta (L/D)} = -5,067 \text{ lbs} \)
Range - \( \frac{\Delta W_{TO}}{\Delta R} = 54.0 \text{ lb/nm} \)
3.7.3 ENGINE SELECTION

The engines were selected using the methods of Chapter 5 in Ref. 2. Two advanced turbo-props were chosen at a power rating of 13,500 shp per engine. The required total shaft horsepower was 26,740 hp. The engine data is given in Appendix B.

3.7.4 WING AND FLAP DESIGN

Table 3.7.1 presents the geometry of the wing and flaps. Parameters such as leading edge sweep and wing thickness were decided by the selection of an NLF airfoil. Appendix C contains the airfoil cross section and airfoil parameters. Wing parameters were selected using the method of Chapter 6 in Ref. 2.

The flaps were sized to $C_{L_{\text{max}}} = 3.0$. This required the use of Fowler flaps. The sizing methods used are contained in Chapter 7 of Ref. 2. The design calculations are in Appendix L, section L.4.

3.7.5 DESIGN OF THE EMPENNAGE

Table 3.7.1 shows the empennage for the 100 passenger airplane. Initially, the V-bar method in chapter 8 of Ref. 2 was used to size the empennage. The design calculations are in Appendix L, section L.5. The initial tail areas that resulted are listed below:

\[ S_H = 347 \text{ ft}^2 \]
\[ S_V = 378 \text{ ft}^2 \]

After the stability and control calculations of Section 3.7.9 were completed, the empennage was resized to:

\[ S_H = 155 \text{ ft}^2 \]
\[ S_V = 303 \text{ ft}^2 \]

These considerations are discussed in section 3.7.9.
3.7.6 CONTROL SURFACE SIZING

3.7.6.1 LATERAL - DIRECTIONAL CONTROLS

Both ailerons and spoilers were used on the 100 passenger regional transport. The geometry of both is contained in Table 3.7.1. This geometry was determined from Chapter 8 of Ref. 2.

The rudder was also sized with the method of Chapter 8 in Ref. 2. The rudder geometry is given in Table 3.7.1.

3.7.6.2 LONGITUDINAL CONTROLS

The elevators for the NASA-100 were sized according to the procedure in Chapter 8 of Ref. 2. Geometric parameters for the elevators are presented in Table 3.7.1.

3.7.7 LANDING GEAR DESIGN

From Chapter 9 of Ref. 2, it was determined that a 30" x 9" tire could be utilized for the nose and main landing gear on every airplane of the commuter family. A preliminary retraction scheme for the main gear is shown in Appendix D. The gear placement was dictated by weight and balance calculations shown in section 3.7.8.

Both the longitudinal and the lateral tip-over criterion were satisfied. Appendix L, section L.6, contains the lateral tip-over calculations.

3.7.8 CLASS I WEIGHT AND BALANCE CALCULATIONS

The weight and balance for the NASA-100 was done after calculating the Class I component weights for the airplane. The component weights were calculated using average weight fractions for the commuter category of airplanes. Appendix F contains the Class I weight fractions for the commuter family. The preliminary weight and balance was then determined using the methods of Chapter 10 in Ref. 2.

The weight breakdown and the center of gravity locations are presented in Table 3.7.4. The center of gravity travel was contained to a range of 36 inches. This travel is approximately 2% of the overall length, or 0.26 \( z \). Figure 3.7.4 diagrams the various center of gravity locations at different airplane weights. Fig. 3.7.4 locates the component cg's on the NASA-100 three-view.

3.7.9 STABILITY AND CONTROL RESULTS

Chapter 11 of Ref. 2 outlines the methods used in the preliminary stability and control calculations. Ref. 5 and
### TABLE 3.7.4—CLASS I WEIGHT AND BALANCE CALCULATION FOR THE 100 PASSENGER COMMUTER.

<table>
<thead>
<tr>
<th>No.</th>
<th>Type of Component</th>
<th>( W_i )</th>
<th>( x_i )</th>
<th>( W_i x_i )</th>
<th>( z_i )</th>
<th>( W_i z_i )</th>
<th>lbs</th>
<th>in</th>
<th>in-lbs</th>
<th>lbs</th>
<th>in</th>
<th>in-lbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Fuselage</td>
<td>14,260</td>
<td>829</td>
<td>1.182x10^7</td>
<td>230</td>
<td>3.280x10^6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Wing</td>
<td>13,043</td>
<td>985</td>
<td>1.285x10^7</td>
<td>212</td>
<td>2.765x10^6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Empennage</td>
<td>3,256</td>
<td>1640</td>
<td>0.534x10^7</td>
<td>488</td>
<td>1.589x10^6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Engine</td>
<td>14,260</td>
<td>1230</td>
<td>1.754x10^7</td>
<td>305</td>
<td>4.349x10^6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Landing gear</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>a. Nose gear</td>
<td>966</td>
<td>246</td>
<td>0.024x10^7</td>
<td>130</td>
<td>0.126x10^6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>b. Main gear</td>
<td>3,862</td>
<td>1005</td>
<td>0.388x10^7</td>
<td>130</td>
<td>0.502x10^6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Fixed eqpt.</td>
<td>16,394</td>
<td>829</td>
<td>1.359x10^7</td>
<td>230</td>
<td>3.771x10^6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Empty weight: \( W_E = 66,042 \text{ lbs} \)

\[ x_{cgW_E} = 988 \text{ in} \]
\[ z_{cgW_E} = 248 \text{ in} \]

7. Trapped fuel and oil \( 561 \) \( 1175 \) \( 6.592x10^5 \) \( 230 \) \( 1.290x10^5 \)

8. Crew \( 820 \) \( 340 \) \( 2.788x10^5 \) \( 230 \) \( 1.886x10^5 \)

Operating empty weight: \( W_{OE} = 67,422 \text{ lbs} \)

\[ x_{cgW_{OE}} = 982 \text{ in} \]
\[ z_{cgW_{OE}} = 248 \text{ in} \]

9. Fuel \( 24,366 \) \( 975 \) \( 2.376x10^7 \) \( 208 \) \( 5.068x10^6 \)

10. Passengers \( 20,500 \) \( 855 \) \( 1.753x10^7 \) \( 230 \) \( 4.715x10^6 \)

Take-off weight: \( W_{TD} = 112,288 \text{ lbs} \)

\[ x_{cgW_{TD}} = 957 \text{ in} \]
\[ z_{cgW_{TD}} = 236 \text{ in} \]

\[ x_{cg} (W_{OE} + \text{Pass}) = 952 \text{ in} \]
\[ x_{cg} (W_{OE} + \text{Fuel}) = 980 \text{ in} \]
FIGURE 3.7.4 CENTER OF GRAVITY EXCURSION DIAGRAM OF THE 100 PASSENGER MODEL

UNIVERSITY OF KANSAS
Ref. 6 were used as supplements for these calculations. Table 3.7.5 contains geometric quantities and stability derivatives necessary to size the empennage for inherent stability. Design calculations are located in Appendix L, section L.7.

3.7.9.1 LONGITUDINAL STABILITY

From methods in Chapter 11 of Ref. 2, the horizontal tail was resized to incorporate a desired static margin of 5%. Appendix L, Figure L.2 presents the longitudinal x-plot for the 100 passenger airplane. From this plot, it is seen that a tail area of 155 ft² is required.

3.7.9.2 LATERAL - DIRECTIONAL STABILITY

From the method of Chapter 11 in Ref. 2, the vertical tail area required to hold engine-out flight was found to be critical. The engines were set at a five degree cant to lessen the thrust moment arm about the cg. The directional x-plot is given in Appendix L, Figure L.3. From this plot, the $c_{nB}$ at the required vertical tail area of 303 ft² was determined.

3.7.10 CLASS I DRAG POLARS

The Class I drag polars were calculated from the procedure of Chapter 12 in Ref. 2. The wetted areas of the airplane components were calculated as presented in Table 3.7.6 and Appendix L, section L.8. From the total airplane wetted area and assuming a skin friction coefficient of 0.0025, $C_D^o$ for the airplane was calculated.

Table 3.7.7 contains the take-off, cruise, and landing drag polars computed during the initial performance sizing. These drag polars are compared to the drag polars computed from wetted area considerations. These Class I drag polars more accurately represent the airplane. Changes to $C_D^o$ for take-off and landing conditions are given in Appendix L, section L.8.

The clean zero-lift drag coefficient at low speed was determined as:

$$C_D^o = 0.0115$$

The drag polars for take-off, landing, and cruise were then calculated as shown in Appendix L.
TABLE 3.7.5--STABILITY AND CONTROL RESULTS FOR THE 100 PASSENGER COMMUTER.

\( S = 1604 \text{ ft}^2; \quad c = 11.6 \text{ ft} \); \( b = 139 \text{ ft} \).

\[ \Delta \bar{x}_{ac_B} = -0.10 \]

\[ \bar{x}_{ac_{WB}} = 0.15 \]

\[ \bar{x}_{ac_A} = 0.506 \quad \text{F.S. : 998} \]

\[ \bar{x}_{ac_H} = 5.60 \]

\[ C_{L_{aW}} = 4.72 \text{ rad}^{-1} \]

\[ C_{L_{aH}} = 3.67 \text{ rad}^{-1} \]

\[ C_{L_{aV}} = 1.66 \text{ rad}^{-1} \]

\[ C_{n_{B}} = 0.0655 \text{ rad}^{-1} \]

\[ \frac{dz}{d\alpha} = 0.162 \]

\[ \bar{x}_{cg_{aft}} = 0.454 \quad \text{F.S. : 988} \]

\( x_v = 57.9 \text{ ft} \).
Assuming a \( C_L_{cr} = 0.3 \), the final drag polars yield:

\[(L/D)_{cr} = 20.4\]

During initial take-off weight sizing, \((L/D)_{cr}\) was assumed to be 16.

The sensitivities to take-off weight given in Table 3.7.3 show that:

\[\frac{\Delta W_{TO}}{\Delta (L/D)} = -5,067 \text{ lbr}\]

For the baseline configuration, this translates into:

\[(L/D)_{cr} = 20.4 - 16 = 4.4\]

\[W_{TO} = \Delta (L/D)_{cr} \frac{\Delta W_{TO}}{\Delta (L/D)} = -22,295 \text{ lbs.}\]

Since the take-off weight is 112,288 lbs, the increase in lift-to-drag ratio causes a 20% decrease in take-off weight. According to Ref. 2, this percentage change in take-off weight indicates that the airplane needs to be resized with the initial weight sizing methods of Ref. 1.
### TABLE 3.7.6--WETTED AREA BREAKDOWN.

<table>
<thead>
<tr>
<th>Component</th>
<th>$S_{\text{wet}}$ (ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Wing</td>
<td>3058</td>
</tr>
<tr>
<td>2. Horizontal tail</td>
<td>320</td>
</tr>
<tr>
<td>3. Vertical tail</td>
<td>626 $c_f = .0025$</td>
</tr>
<tr>
<td>4. Fuselage</td>
<td>2937 $f = 18.5$ ft²</td>
</tr>
<tr>
<td>5. Engines</td>
<td>248</td>
</tr>
<tr>
<td>6. Engine pylons</td>
<td>278</td>
</tr>
<tr>
<td>Total</td>
<td>7467</td>
</tr>
</tbody>
</table>

### TABLE 3.7.7--DRAG POLAR COMPARISON.

<table>
<thead>
<tr>
<th>Preliminary Results</th>
<th>Drag Polar</th>
<th>$(L/D)_{\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Clean</td>
<td>$0.0196 + 0.0312C_L^2$</td>
<td>20.2</td>
</tr>
<tr>
<td>2. Take-off, gear up</td>
<td>$0.0346 + 0.0332C_L^2$</td>
<td>14.7</td>
</tr>
<tr>
<td>3. Take-off, gear down</td>
<td>$0.0546 + 0.0332C_L^2$</td>
<td>11.7</td>
</tr>
<tr>
<td>4. Landing, gear up</td>
<td>$0.0946 + 0.0332C_L^2$</td>
<td>8.9</td>
</tr>
<tr>
<td>5. Landing, gear down</td>
<td>$0.1146 + 0.0332C_L^2$</td>
<td>8.1</td>
</tr>
</tbody>
</table>

$(L/D)_{\text{cruise at } C_L = 0.3} = 13.4$

### Class I Results

| 1. Clean            | $0.0119 + 0.0312C_L^2$ | 25.9                  |
| 2. Take-off, gear up | $0.0269 + 0.0332C_L^2$ | 16.7                  |
| 3. Take-off, gear down | $0.0469 + 0.0332C_L^2$ | 12.7                  |
| 4. Landing, gear up | $0.0869 + 0.0332C_L^2$ | 9.3                   |
| 5. Landing, gear down | $0.1069 + 0.0332C_L^2$ | 8.4                   |

$(L/D)_{\text{cruise at } C_L = 0.3} = 20.4$
3.7.11 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions resulted from the preliminary design work on the NASA-100:

1. \[ W_{TD} = 112,288 \text{ lbs}; \ W_{E} = 66,042 \text{ lbs}; \ W_{OE} = 67,422 \text{ lbs} \]

2. Powerplant: Two 13,500 lb turboprops, aft-mounted.

3. Commonality achieved:
   a. fuselage cross-section.
   b. cockpit layout.
   c. landing gear.
   d. natural laminar flow airfoils.

4. Achieved inherent longitudinal and directional stability.

5. The take-off weight will decrease by 20\% due to high (L/D) characteristics, but it may increase due to the structural weight of high aspect ratio wings.

6. Wing-folding may need to be employed in order to meet existing gate requirements.

The following recommendations resulted from the preliminary design work:

1. The feasibility of folding the wings needs to be analyzed.

2. The 100 passenger airplane will need to be resized according to the methods of Ref. 1.

3. The feasibility of achieving a common wing torque box needs further study, but will be difficult to achieve.

4. This configuration should be replaced with the 100 passenger twin-body model. More commonality appears possible with the twin-body configuration. The twin-body model also has the advantage of a lighter take-off weight.
4.0 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 and cabin and baggage volumes of the airplanes will be compared. These comparisons will attempt to prove the validity of the class I designs.

4.1 COMPARISON OF TAKE-OFF WEIGHTS

Figure 4.1 shows that the commuter family take-off weights compared with existing airplanes. The commuter family was sized assuming a 5% empty weight savings due to the use of advanced structural materials. Aramid Aluminum will be utilized to achieve this empty weight savings. Appendix E contains data for this composite material.

4.2 CENTER OF GRAVITY EXCURSION

Table 4.1 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 2.

From Table 4.1 it can be seen that all the class I designs have C.G. excursion ranges comparable with contemporary airplanes. The large range of C.G. travel for the twin-body 75 passenger airplane is due to commonality constraints with the 36 passenger design.

4.3 COMPARISON OF AIRPLANE WETTED AREAS

Wetted areas of the commuter family are compared to regional turbo-propeller and jet transports wetted areas. Figure 4.2a compares the wetted areas of the smaller passenger capacity airplanes. Figure 4.2b compares the larger capacity airplanes. It can be seen that these airplanes compare favorably with existing regional turbo-propeller and jet transport airplanes.

4.4 COMPARISON OF AIRPLANE WING LOADINGS

Wing loadings of the commuter family are compared to existing commuters and jet transports. Table 4.2 lists wing loadings of some existing airplanes. Table 4.3 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.
### TABLE 4.1 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>21&quot; .28c</td>
<td>12&quot;-20&quot; .14 - .27c</td>
</tr>
<tr>
<td>36 passenger</td>
<td>20&quot; .25c</td>
<td>12&quot;-20&quot; .14 - .27c</td>
</tr>
<tr>
<td>50 passenger</td>
<td>15&quot; .17c</td>
<td>12&quot;-20&quot; .14 - .27c</td>
</tr>
<tr>
<td>75 passenger</td>
<td>21&quot; .17c</td>
<td>26&quot;-91&quot; .12 - .32c</td>
</tr>
<tr>
<td>100 passenger</td>
<td>30&quot; .21c</td>
<td>26&quot;-91&quot; .12 - .32c</td>
</tr>
<tr>
<td>75 twin-body</td>
<td>31&quot; .34c</td>
<td>26&quot;-91&quot; .12 - .32c</td>
</tr>
<tr>
<td>100 twin-body</td>
<td>16&quot; .16c</td>
<td>26&quot;-91&quot; .12 - .32c</td>
</tr>
</tbody>
</table>

### TABLE 4.2 WING LOADINGS OF EXISTING AIRPLANES

<table>
<thead>
<tr>
<th>Airplane Model</th>
<th>(W/S) TQ psf</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASA C-212-200</td>
<td>38.1</td>
</tr>
<tr>
<td>Shorts 330</td>
<td>50.5</td>
</tr>
<tr>
<td>Beech 1900</td>
<td>50.3</td>
</tr>
<tr>
<td>Fokker F27-200</td>
<td>59.7</td>
</tr>
<tr>
<td>DHC-6-300</td>
<td>29.8</td>
</tr>
<tr>
<td>DHC-7</td>
<td>66.5</td>
</tr>
<tr>
<td>DHC-8</td>
<td>52.1</td>
</tr>
<tr>
<td>EMB-120</td>
<td>51.7</td>
</tr>
<tr>
<td>BAe 31</td>
<td>53.9</td>
</tr>
<tr>
<td>METRO III</td>
<td>46.9</td>
</tr>
<tr>
<td>Fokker F-28</td>
<td>85.9</td>
</tr>
<tr>
<td>BAe 146-200</td>
<td>107.6</td>
</tr>
</tbody>
</table>

### TABLE 4.3 WING LOADINGS FOR THE COMMUTER FAMILY

<table>
<thead>
<tr>
<th>Airplane Model</th>
<th>(W/S) TQ psf</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 Passenger</td>
<td>50</td>
</tr>
<tr>
<td>36 Passenger</td>
<td>70</td>
</tr>
<tr>
<td>50 Passenger</td>
<td>70</td>
</tr>
<tr>
<td>75 Passenger</td>
<td>70</td>
</tr>
<tr>
<td>100 Passenger</td>
<td>70</td>
</tr>
<tr>
<td>75 Twin-Body</td>
<td>84</td>
</tr>
<tr>
<td>100 Twin-Body</td>
<td>87</td>
</tr>
</tbody>
</table>
FIGURE 4.1 TAKE-OFF WEIGHT COMPARISON

Copied from Ref. 1.
Figure 4.2 Wetted Area Comparison
Copied from Ref. 1.
### 4.5 COMPARISON OF CABIN VOLUME WING EXISTING AIRPLANES

Passenger and baggage volume are compared with existing airplanes in Table 4.4. Data for Table 4.4 is compiled from Reference 8, Appendix B.

**TABLE 4.4 COMPARISON OF CABIN AND BAGGAGE VOLUMES**

<table>
<thead>
<tr>
<th>Airplane Type</th>
<th>Number of Passengers</th>
<th>Overhead Baggage Volume (cuft) per Seat (cuft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>56</td>
</tr>
<tr>
<td>36</td>
<td>36</td>
<td>41</td>
</tr>
<tr>
<td>25</td>
<td>25</td>
<td>29</td>
</tr>
<tr>
<td>British</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerospace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAe Super 748</td>
<td>46</td>
<td>41</td>
</tr>
<tr>
<td>BAe ATP</td>
<td>48</td>
<td>100</td>
</tr>
<tr>
<td>BAe 146-100</td>
<td>64</td>
<td>56</td>
</tr>
<tr>
<td>de Havilland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DASH 7</td>
<td>50</td>
<td>59</td>
</tr>
<tr>
<td>DASH 8</td>
<td>37</td>
<td>32</td>
</tr>
<tr>
<td>Fokker</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F-27</td>
<td>52</td>
<td>40</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>79</td>
</tr>
<tr>
<td>F-28</td>
<td>65</td>
<td>107</td>
</tr>
<tr>
<td>Shorts</td>
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<td></td>
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<tr>
<td>330</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>360</td>
<td>36</td>
<td>52</td>
</tr>
<tr>
<td>ATR Consortium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATR 42-200</td>
<td>46</td>
<td>53</td>
</tr>
<tr>
<td>Embraer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EMB-120</td>
<td>30</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.0 Commonality Analysis of the Commuter Family

Now that the Class I designs for the commuter family have been presented, the extent of commonality that was implemented needs to be discussed. Table 5.1 shows the status of the commonality objectives listed in Chapter 2.

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

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.

These features were implemented with a minimum of configuration design problems.

To also achieve:


the twin-body configurations were introduced. This allowed the above objectives to be integrated into the commuter family. The wing areas of the 75 and 100 passenger conventional configurations were too large to implement a common torque box carry-through structure. See Table 2.3. 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 has 4 tires per bogey on the main gear, while the twin-body 100 passenger only needed 2 wheels per bogey. See Table 2.4.

From reasons discussed in Appendix B, two different shp turbo-prop engines will be used to span the passenger models presented in Chapter 3. Table 5.1 shows what engines are integrated into the airplanes of the family.

From the Class I drag polar analysis conducted in Chapter 4, it was determined that to achieve the desired \( \frac{L}{D} \) values, the 12 aspect ratio wing will be needed. Therefore, the weight penalty of the wing design is necessary.

Empennage and tailcone commonality is desired. Design work necessary to complete a proposal for these items has not been completed yet. Handling qualities results and Class II weight and balance results will be required to submit a commonality proposal for the empennage and tailcone arrangement.

Systems commonality will require further study. For the flight control system design, the open loop handling qualities will be examined and common closed loop
Table 5.1--Status of Commonality in the Commuter Family.

<table>
<thead>
<tr>
<th>Aircraft Type</th>
<th>25 Pax</th>
<th>36 Pax</th>
<th>50 Pax</th>
<th>75 Pax</th>
<th>100 Pax</th>
<th>75 Pax</th>
<th>100 Pax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuselage Tailcone Arrangement</td>
<td>Yes</td>
<td>Yes</td>
<td>Further design work is required.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wing Torque Box</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</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>
<td>Yes</td>
</tr>
<tr>
<td>Landing Gear</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Systems Commonality</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</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>
<td>Yes</td>
</tr>
<tr>
<td>Handling Qualities</td>
<td>Yes</td>
<td>Yes</td>
<td>Further design work is required.</td>
<td></td>
<td></td>
<td></td>
<td></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>
<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>
<td>Yes</td>
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<td>Pressurization</td>
<td>Yes</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>
<td>Yes</td>
</tr>
<tr>
<td>Engine Commonality</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</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>
<td>Yes</td>
</tr>
<tr>
<td>6000 shp</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>13,500 shp</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
characteristics will be proposed. A separate surface stability augmentation system (SSSA) will be proposed. Also a fly by wire flight control system using electro-hydrostatic actuators will be researched.

The critical wing L.E. volume of the 25 passenger model will be implemented with a T.K.S. de-icing system. This system will then be able to fit into all the other airplanes in the family.
6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

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

2) Take-off weights range from 21046 lbs to 112288 lbs.

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

4) Five designs have been selected to be taken through the class II design procedure:
   a) 25 passenger
   b) 36 passenger
   c) 75 twin-body
   d) 50 passenger
   e) 100 twin-body

5) The following commonality objectives have been integrated into the commuter family:
   - Common fuselage cross section
   - Common landing gear tire sizes
   - Common main and nose gear retraction schemes
   - Common wing torque boxes
   - Common powerplants (2)
   - Common cockpit instrumentation
   - Common NLF airfoil

6.2 RECOMMENDATIONS

1) Continue design work on the 25, 36, and 50 passenger models. The twinbody 75 and 100 passenger models should also be taken through some class II design methods.

2) Determine handling characteristics of the commuter family. This will allow for the design of a flight control system that will achieve handling commonality across the passenger range.

3) Propose a common empennage-tailcone arrangement.

4) Propose designs for common flight and operational systems.
7. REFERENCES


APPENDIX A

COCKPIT AND FUSELAGE ARRANGEMENTS
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A.1 FUSELAGE CROSS SECTION
   A.1.1 Determination of Overhead Baggage Volume A.3
A.2 COCKPIT LAYOUT A.5
A.3 CABIN LAYOUTS A.10
A.11
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
Area of Sector = \( \frac{1}{2} r^2 \theta \) (\( \theta \) in radians)

= \( \frac{1}{2} (2.26)^2 (39.5) \cdot \frac{\pi}{180} \)

= 1.76 in\(^2\)
**AREA OF TRIANGLE A:**

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

\[ \alpha = 34.2^\circ \quad \Rightarrow \quad h = 0.22 \text{ in} \]

**AREA OF TRIANGLE B:**

\[ \alpha = 67.6^\circ \quad \Rightarrow \quad h = 0.92 \text{ in} \]

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

**AREA OF TRIANGLE C:**

\[ \alpha = 40^\circ \quad \Rightarrow \quad h = 0.28 \text{ in} \]

\[ A = \frac{1}{2}bh = \frac{1}{2}(2.26 \times 0.28) = 0.32 \text{ in}^2 \]
Area of Overhead Storage

\[ A = (1.76 \text{ in}^2) - (0.25 \text{ in}^2) - (0.90 \text{ in}^2) - (0.32 \text{ in}^2) \]
\[ A = 0.29 \text{ in}^2 \]
\[ A = 116 \text{ in}^2 = 0.81 \text{ ft}^2 \]

50 Passenger Overhead Volume

\[ V = (0.81 \text{ ft}^2)(0.5 \text{ in})(50 \text{ in/ft}) + (0.81 \text{ ft}^2)(8 \text{ in})(50 \text{ in/ft}) \]
\[ (12 \text{ in/ft}) \]

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

36 Passenger Overhead Volume

\[ V = (0.81 \text{ ft}^2)(6.1 \text{ in})(50 \text{ in/ft})(2 \text{ rows}) \]
\[ (12 \text{ in/ft}) \]

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

25 Passenger Overhead Volume

\[ V = (0.81 \text{ ft}^2)(4.3 \text{ in})(50 \text{ in/ft})(2 \text{ rows}) \]
\[ (12 \text{ in/ft}) \]

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

Figure A.1 lists the overhead volume per passenger of the 25, 36, and 50 passenger commuter airplanes along with the values for other commuter airplanes for comparison.
<table>
<thead>
<tr>
<th>Airplane Type</th>
<th>Number of Passengers</th>
<th>Overhead Baggage 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</td>
<td>50</td>
<td>56</td>
<td>1.1</td>
</tr>
<tr>
<td>36</td>
<td>36</td>
<td>41</td>
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<tr>
<td>25</td>
<td>25</td>
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<td>1.2</td>
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<td>British</td>
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</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>
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<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>
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<td>50</td>
<td>50</td>
<td>79</td>
<td>1.6</td>
</tr>
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<td>F-28</td>
<td>65</td>
<td>107</td>
<td>1.6</td>
</tr>
<tr>
<td>Shorts</td>
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<td></td>
</tr>
<tr>
<td>330</td>
<td>30</td>
<td>40</td>
<td>1.3</td>
</tr>
<tr>
<td>360</td>
<td>36</td>
<td>52</td>
<td>1.4</td>
</tr>
<tr>
<td>ATR Consortium</td>
<td></td>
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</tr>
<tr>
<td>ATR 42-200</td>
<td>46</td>
<td>53</td>
<td>1.2</td>
</tr>
<tr>
<td>Embraer</td>
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<td></td>
</tr>
<tr>
<td>EMB-120</td>
<td>30</td>
<td>32</td>
<td>1.1</td>
</tr>
</tbody>
</table>
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.
Statement of Purpose:

The purpose of this appendix is to provide the engine data and configuration used throughout this study.
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1. Engine Data Source ................................................................. B-1
2. Engine Selection Criteria ......................................................... B-1
3. 6,000 SHP Engine Data ............................................................. B-1
4. 13,500 SHP Engine Data ............................................................. B-2
5. Installation Characteristics ......................................................... B-2
1. Engine Data Source

The engine data used in this report are taken from ADVANCED PROPFAN ENGINE TECHNOLOGY (APET) AND SINGLE AND COUNTER-ROTATION GEARBOX/PITCH CHANGE MECHANISM. NASA CR-168115, by Allison Gas Turbine Division, General Motors Corporation.

The study engine falls under the designation PD436-11. The technology in this propulsion system is verifiable in the late 1980's and is appropriate for production in the mid 1990's.

Two engines for this study have been scaled from the APET report: a 6000 shp engine and a 13,500 shp engine. The baseline engine is shown in Figure B.1.

2. Engine Selection Criteria

The initial criteria proposed for selecting a propulsion system for the commuter family was as follows:

* 2 powerplants per airplane
* aft-mounted pusher configurations
* one common engine core used throughout

Due to the wide range of power levels required between the 25 and 100 passenger airplanes (4210 - 13400 shp), it was decided to use two different engine cores:

- 6000 shp engine core: for the 25, 35, and 50 passenger configurations
- 13,500 shp engine core: for the 75 and 100 passenger twin body configurations

Obviously, the 25 passenger design will be overpowered by 30 percent, but the engine can be "flat-rated" to meet the airplane's maximum needs. This means the 25, 36, and 75 passenger designs will carry an extra weight penalty.

3. 6,000 SHP Engine Data

Dimensions:

- Overall length: 108.5 inches
- Maximum height: 35.4 inches
- Maximum width: 26.2 inches
- Maximum engine diameter: 24.9 inches
- Reduction gearbox diameter: 36.4 inches
Weight:

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine weight</td>
<td>879 lbs</td>
</tr>
<tr>
<td>Reduction gearbox and</td>
<td>308 lbs</td>
</tr>
<tr>
<td>interconnecting structure</td>
<td></td>
</tr>
<tr>
<td>Propeller weight</td>
<td>1690 lbs</td>
</tr>
<tr>
<td>Nacelle weight</td>
<td>964 lbs</td>
</tr>
</tbody>
</table>

Performance:

Sea level, standard day at maximum power:

- Power = 6204 shp
- sfc = 0.368 lbs/hp/hr

4. **13,500 SHP Engine Data**

Dimensions:

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall length</td>
<td>158.1 inches</td>
</tr>
<tr>
<td>Maximum height</td>
<td>48.9 inches</td>
</tr>
<tr>
<td>Maximum width</td>
<td>36.2 inches</td>
</tr>
<tr>
<td>Maximum engine diameter</td>
<td>37.3 inches</td>
</tr>
<tr>
<td>Reduction gearbox diameter</td>
<td>54.6 inches</td>
</tr>
</tbody>
</table>

Weight:

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine weight</td>
<td>1,995 lbs</td>
</tr>
<tr>
<td>Reduction gearbox and</td>
<td>1,848 lbs</td>
</tr>
<tr>
<td>interconnecting structure</td>
<td></td>
</tr>
<tr>
<td>Propeller weight</td>
<td>1,698 lbs</td>
</tr>
<tr>
<td>Nacelle weight</td>
<td>1,368 lbs</td>
</tr>
</tbody>
</table>

Performance:

Sea level, standard day at maximum power:

- Power = 13,457 shp
- sfc = 0.357 lbs/hp/hr

5. **Installation Characteristics**

The following dimensions are related to Figure B.2. The installation data is for a counter-rotation pusher propfan (6x6 blades) for Mcruise = 0.70.

- \( L_s = 0.55D \)
- \( L_{cg} = 0.09D \)
- \( d = 0.25D \)
- \( F_{bf} = 1.5BL \)

where, \( D \) - Blade diameter
BL - Blade length
Figure B.1 PD436-11 Powerplant

Note: All dimensions are in inches
APPENDIX C

AIRFOIL DATA
C.1 SUMMARY

This appendix details the procedure, and decisions made in determining realistic NLF airfoil section data. The design conditions for the airfoil are:

1) Drag Divergence Mach Number of .75
2) Design Lift Coefficient of .40

The airfoil section described herein is a paper airfoil. It is modeled after the HSNLF(1)-0213 airfoil designed by J. Viken at NASA Langley. To obtain actual data, extensive computer analysis and wind tunnel tests would be needed, which are beyond the scope of this project.

The assumed airfoil characteristics are:

\[ \frac{t}{c} = 0.117 \quad \text{(unswept)} \]
\[ \frac{t}{c} = 0.129 \quad \text{(swept 20°)} \]
\[ C_{1_{\text{max}}} = 1.6 \]
\[ C_{d_{\text{min}}} = 0.0035 \quad \text{(low speed)} \]
\[ C_{d_{\text{min}}} = 0.0075 \quad \text{(cruise M=0.70)} \]
\[ C_{1_{a}} = 0.105 \quad \text{deg}^{-1} \]
\[ C_{m_{ac}} = -0.10 \]
\[ M_{\text{dd}} = 0.75 \]
Appendix D

Class I Landing Gear Retraction Scheme
D. **Class I Landing Gear Retraction Scheme**

This section presents the retraction kinematics for the landing gear of the family of commuter transports.

From Reference 2 a preliminary tire choice was made with the following dimensions:

\[ \text{Do} = 30 \text{ inches} \quad \text{W} = 8.8 \text{ inches} \]

To achieve complete stowage of the nose gear a retraction scheme which incorporated the tires turning 90 degrees relative to the main strut was required. Figure D.1 shows the retraction kinematics for the nose gear.

The main gear could not be stowed within the fuselage. Figure D.2 shows the retraction kinematics for the main gear and the modification made to house the main gear.

The Class II landing gear analysis may result in some changes to the landing gear as proposed here. These changes are believed to be, increase the number of tires on the main landing gear from two to four or use two different tires, one for the nose gear and one type for the main gear.
APPENDIX E

ARAMID ALUMINUM DATA SUMMARY
Table of Contents

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

<table>
<thead>
<tr>
<th>Property</th>
<th>2024T3</th>
<th>7075T6</th>
<th>ARALL*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2% Yield Stress (KSI)</td>
<td>52</td>
<td>70</td>
<td>77</td>
</tr>
<tr>
<td>Ultimate Tensile Stress (KSI)</td>
<td>68</td>
<td>81</td>
<td>114</td>
</tr>
<tr>
<td>Proportional Limit Comp. (KSI)</td>
<td>39</td>
<td>70</td>
<td>47</td>
</tr>
<tr>
<td>Youngs Modulus (KSI)</td>
<td>10440</td>
<td>10440</td>
<td>9135</td>
</tr>
<tr>
<td>Failure Strain %</td>
<td>17</td>
<td>11</td>
<td>3.5</td>
</tr>
<tr>
<td>Specific Weight</td>
<td>2.8</td>
<td>2.8</td>
<td>2.45</td>
</tr>
<tr>
<td>Density lb/ft³</td>
<td>174.8</td>
<td>174.8</td>
<td>152.95</td>
</tr>
</tbody>
</table>

*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

CLASS I WEIGHT FRACTIONS FOR THE COMMUTER FAMILY
The purpose of this appendix is to present the class I weight fractions for the airplane family components. These weight fractions were compiled from weight data in Reference 7. Table F.1 displays the airplanes used to compile the database and the weight fractions for the commuter family.

### TABLE F.1 CLASS I WEIGHT FRACTIONS

<table>
<thead>
<tr>
<th>Component</th>
<th>Fokker F-27-200</th>
<th>Fokker F-27-500</th>
<th>DeHavilland DHC7-102</th>
<th>DHC6-300 Family</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuselage</td>
<td>.099</td>
<td>.114</td>
<td>.106</td>
<td>.136</td>
</tr>
<tr>
<td>Wing</td>
<td>.104</td>
<td>.100</td>
<td>.111</td>
<td>--</td>
</tr>
<tr>
<td>Empennage</td>
<td>.024</td>
<td>.024</td>
<td>.030</td>
<td>.024</td>
</tr>
<tr>
<td>Powerplant</td>
<td>--</td>
<td>--</td>
<td>.107</td>
<td>.100</td>
</tr>
<tr>
<td>Landing Gear</td>
<td>.042</td>
<td>.041</td>
<td>.039</td>
<td>--</td>
</tr>
<tr>
<td>Fixed Eqpt.</td>
<td>--</td>
<td>.144</td>
<td>.169</td>
<td>.145</td>
</tr>
</tbody>
</table>
APPENDIX G

WING TORQUE BOX COMMONALITY
G.1 STATEMENT OF PURPOSE

The primary objective of this Appendix is to determine the location of the front spar and the rear spar such that the chord lengths of the wing torque boxes of the 25, 36, and 50 passenger airplanes are equal in length. Table G.1 lists the wing geometries.

### Table G.1 Commuter Family Wing Geometries

<table>
<thead>
<tr>
<th>Wing Area ft²</th>
<th>25 pax</th>
<th>36 pax</th>
<th>50 pax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect Ratio</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Wing Span ft</td>
<td>71.1</td>
<td>73.4</td>
<td>84.2</td>
</tr>
<tr>
<td>Root Chord ft</td>
<td>8.46</td>
<td>8.74</td>
<td>10.0</td>
</tr>
<tr>
<td>Taper Ratio</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Of these different wing configurations the length of the torque box was limited by the wing root chord length of the 25 passenger commuter. The results are listed in Table G.2. See Figure 2.4 for the wing overlays with the common torque box structure shown.

### Table G.2 Wing Spar Location

<table>
<thead>
<tr>
<th>Passenger Model</th>
<th>Front Spar</th>
<th>Rear Spar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Root</td>
<td>Tip</td>
</tr>
<tr>
<td>25</td>
<td>.080</td>
<td>.080</td>
</tr>
<tr>
<td>36</td>
<td>.075</td>
<td>.084</td>
</tr>
<tr>
<td>50</td>
<td>.110</td>
<td>.130</td>
</tr>
</tbody>
</table>
APPENDIX H

ENGINEERING CALCULATIONS FOR THE
25 PASSENGER COMMUTER
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>H.1</td>
<td>Introduction</td>
<td>H-3</td>
</tr>
<tr>
<td>H.2</td>
<td>Preliminary Weight Sizing</td>
<td>H-4</td>
</tr>
<tr>
<td>H.3</td>
<td>Preliminary Performance Sizing</td>
<td>H-6</td>
</tr>
<tr>
<td>H.4</td>
<td>Class I Flap Sizing</td>
<td>H-12</td>
</tr>
<tr>
<td>H.5</td>
<td>Class I Empennage Sizing</td>
<td>H-15</td>
</tr>
<tr>
<td>H.6</td>
<td>Landing Gear Criterion</td>
<td>H-17</td>
</tr>
<tr>
<td>H.7</td>
<td>Stability And Control Calculations</td>
<td>H-19</td>
</tr>
<tr>
<td>H.8</td>
<td>Class I Drag Polars</td>
<td>H-33</td>
</tr>
</tbody>
</table>
H.1 Introduction

The purpose of this Appendix is to present the preliminary sizing and Class I design calculations for the 25 passenger commuter. Methods used were taken from References 1 and 2. References 5 and 6 were used for stability and control design calculations.

Section H.2 contains preliminary weight sizing calculations. These results are from XENWTOG, a computer program available at Kansas University.

Section H.3 contains preliminary performance results from XPRFRM, a computer interactive program available at the University of Kansas.

Section H.4 contains Class I flap sizing calculations.
Section H.5 contains Class I empennage sizing (N-method).
Section H.6 contains landing gear design criteria.
Section H.7 contains stability and control calculations.
Section H.8 contains the wetted area calculations and the Class I Prag Polars.
H.2 Initial Weight Sizing

Using XEWTG, a weight sizing program which follows the method in Ch 2 of REF 1, the following weights and take-off weight sensitivities for the 25 passenger airplane were determined.

See Table J.1.

The design assumptions used in the weight sizing were:

\[(\frac{C}{D})_{cr} = 16\]

\[C_F = 0.4 \text{ lb/Hp/HR}\]

\[N_p = 0.85\]

\[V_{cr} = 442 \text{ Knts}\]
### Table H.1: Initial Weight Sizing Results with Sensitivity

<table>
<thead>
<tr>
<th>Phase</th>
<th>W/W</th>
<th>CJ Gr CP</th>
<th>L/D</th>
<th>AltCR</th>
<th>RC</th>
<th>MCP</th>
<th>OF</th>
<th>Y</th>
<th>E Or F</th>
<th>PLCRCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.695</td>
<td>0.00</td>
<td>C:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>C</td>
</tr>
<tr>
<td>2</td>
<td>0.695</td>
<td>0.00</td>
<td>C:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>C</td>
</tr>
<tr>
<td>3</td>
<td>0.695</td>
<td>0.00</td>
<td>C:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>C</td>
</tr>
<tr>
<td>4</td>
<td>0.695</td>
<td>0.00</td>
<td>C:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>C</td>
</tr>
<tr>
<td>5</td>
<td>0.695</td>
<td>0.00</td>
<td>C:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>C</td>
</tr>
<tr>
<td>6</td>
<td>0.695</td>
<td>0.00</td>
<td>C:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>C</td>
</tr>
</tbody>
</table>

Regression coefficients are A=0.3985 and B=0.05647.

The mission fuel fraction without reserves is 0.257.

The gross take-off weight is 21500 PCUACs.

The empty weight is 11954 PCUACs.

The weight of fuel is 3645 pounds.

**Unempty weight reduction due to components: 5.0 per cent**

**Sensitivity analysis begins here.**

**Growth factor due to payload weight is 1.0.**

**The take-off weight to empty weight sensitivity is 1.3.**

**Choice Number:**

<table>
<thead>
<tr>
<th>SFC (LB/LB/Hr)</th>
<th>Prop Efficiency</th>
<th>L/D</th>
<th>Velocity (Knts)</th>
<th>Range (Mt. Miles)</th>
<th>Endurance (Hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.0</td>
<td>16.0</td>
<td>1100</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

The sensitivity of gross take-off weight to the following parameters is now given as the partial derivative of the gross take-off weight to the indicated parameter.

<table>
<thead>
<tr>
<th>DWT/DC (LB/LB/LB/Hr)</th>
<th>DWT/DC (LB/LB/PC/Hr)</th>
<th>DWT/DC (Pounds)</th>
<th>DWT/DC (L/D) (Pounds)</th>
<th>DWT/DC (Lb/Knot)</th>
<th>DWT/DC (Lb/Mile)</th>
<th>CWT/DE (Lb/Pr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.56</td>
<td>0.25</td>
<td>1.25</td>
<td>-0.53</td>
<td>0.06</td>
<td>0.04</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Original Page is 05 Book Quality.
H 3 Initial Performance Sizing

The results from XPRFRM, a performance sizing program, are presented in this section. The methods used are presented in Ch 3 of Ref 2.

The results are presented in Tables H.3 through H.6.
**TABLE H.2**

******** TAKE-OFF SIZING ********

"FAR 25 CERTIFICATION CATEGORY"

REGIONAL TLRBC-PRCP

PROPELLER GIVEN

--- INPUT DATA ---

<table>
<thead>
<tr>
<th>ALTITUDE</th>
<th>TAKE-OFF DISTANCE (STC)</th>
<th>LIFT COEFFICIENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2G.00</td>
<td>18.6</td>
<td>2.56</td>
</tr>
<tr>
<td>4C.00</td>
<td>24.2</td>
<td>14.6</td>
</tr>
<tr>
<td>6C.00</td>
<td>33.2</td>
<td>11.5</td>
</tr>
<tr>
<td>8C.00</td>
<td>3.6</td>
<td>19.5</td>
</tr>
<tr>
<td>100.00</td>
<td>3.8</td>
<td>5.8</td>
</tr>
</tbody>
</table>

--- OUTPUT DATA ---

**TABLE OF FLIGHT LOADINGS**

<table>
<thead>
<tr>
<th>W/S</th>
<th>CLMAX-TC</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.G.C</td>
<td>1.4C</td>
</tr>
<tr>
<td>2G.00</td>
<td>18.6</td>
</tr>
<tr>
<td>4C.00</td>
<td>24.2</td>
</tr>
<tr>
<td>6C.00</td>
<td>33.2</td>
</tr>
<tr>
<td>8C.00</td>
<td>3.6</td>
</tr>
</tbody>
</table>

**TABLE H.3** Landing Field Length Sizing

REGIONAL TLRBC-PRCP

FAR 25 CERTIFICATION CATEGORY

<table>
<thead>
<tr>
<th>GROSS TAKE-OFF WEIGHT (MT)</th>
<th>21046.0 (LBS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LANDING TO TAKE-OFF WEIGHT RATIO</td>
<td>1.00</td>
</tr>
<tr>
<td>ALTITUDE</td>
<td>C.G.C (FEET)</td>
</tr>
<tr>
<td>C.G.C</td>
<td>23769.0 (SLUG/FT**3)</td>
</tr>
<tr>
<td>1000.00</td>
<td>3500.0 (C.FEET)</td>
</tr>
</tbody>
</table>

(W/S)TO = 23.4CCLMAX(LAND)

MAXIMUM TAKE-OFF WING LOADINGS TO MEET LANDING DISTANCE REQUIREMENT

<table>
<thead>
<tr>
<th>CLMAX</th>
<th>MAXIMUM WING LOAD (LB/FT**2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(LAND)</td>
<td>(TAKE-OFF)</td>
</tr>
<tr>
<td>1.4C</td>
<td>32.77</td>
</tr>
<tr>
<td>2.2C</td>
<td>51.46</td>
</tr>
<tr>
<td>2.6C</td>
<td>64.85</td>
</tr>
</tbody>
</table>
**DRAG FCLAR ECLATIONS**

***INPUT DATA***

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Take-Off Weight (Clean)</td>
<td>21460.0 LBS</td>
</tr>
<tr>
<td>Wing Area</td>
<td>425.00 FT^2</td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td>12.00</td>
</tr>
<tr>
<td>Skin Friction Coefficient</td>
<td>0.00CC</td>
</tr>
<tr>
<td>Airplane Wetted Area</td>
<td>20.00CC</td>
</tr>
<tr>
<td>Drag Increment Due to Take-Off Flaps</td>
<td>0.00CC</td>
</tr>
<tr>
<td>Drag Increment Due to Landing Flaps</td>
<td>0.00CC</td>
</tr>
<tr>
<td>Drag Increment Due to Landing Gear</td>
<td>0.00CC</td>
</tr>
<tr>
<td>Oscalps Efficiency Factor (Clean)</td>
<td>0.00CC</td>
</tr>
<tr>
<td>Oscalps Efficiency Factor (Take-Off)</td>
<td>0.00CC</td>
</tr>
<tr>
<td>Oscalps Efficiency Factor (Landing)</td>
<td>0.00CC</td>
</tr>
</tbody>
</table>

***CALCULATED DATA***

The complete set of drag FCLARS is:

1. Low-Speed (Clean):
   \[ C_D = 0.0258 + 0.0332CC \] \[ L/C_{max} = 19.63 \]

2. Take-Off (Landing Gear LF):
   \[ C_D = 0.0458 + 0.0332CC \] \[ L/C_{max} = 13.60 \]

3. Take-Off (Landing Gear CCW):
   \[ C_D = 0.0558 + 0.0332CC \] \[ L/C_{max} = 11.63 \]

4. Landing (Landing Gear LF):
   \[ C_D = 0.0858 + 0.0332CC \] \[ L/C_{max} = 9.066 \]

5. Landing (Landing Gear CCW):
   \[ C_D = 0.0958 + 0.0332CC \] \[ L/C_{max} = 8.87 \]
### Table H.5a)

**FAR 25.111 (CEI) "INITIAL CLIMB SEGMENT"**

**FAR 25.111 CLIMB GRADIENT (INITIAL SEGMENT) 1.200C**

<table>
<thead>
<tr>
<th>WING LOADING (LB/FT²)</th>
<th>20.00</th>
<th>40.00</th>
<th>60.00</th>
<th>80.00</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPECT RATIO 1.00</td>
<td>72.72</td>
<td>51.44</td>
<td>41.99</td>
<td>36.36</td>
<td>36.36</td>
</tr>
<tr>
<td>1.20</td>
<td>73.43</td>
<td>52.14</td>
<td>42.66</td>
<td>37.01</td>
<td>37.01</td>
</tr>
<tr>
<td>1.40</td>
<td>74.14</td>
<td>52.84</td>
<td>43.33</td>
<td>37.66</td>
<td>37.66</td>
</tr>
<tr>
<td>1.60</td>
<td>74.85</td>
<td>53.54</td>
<td>44.00</td>
<td>38.32</td>
<td>38.32</td>
</tr>
</tbody>
</table>

### Table H.5b)

**FAR 25.121 (CEI) "SECOND SEGMENT CLIMB"**

**FAR 25.121 CLIMB GRADIENT (SECOND SEGMENT) 2.400C**

<table>
<thead>
<tr>
<th>WING LOADING (LB/FT²)</th>
<th>20.00</th>
<th>40.00</th>
<th>60.00</th>
<th>80.00</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPECT RATIO 1.00</td>
<td>64.77</td>
<td>47.86</td>
<td>37.46</td>
<td>32.16</td>
<td>32.16</td>
</tr>
<tr>
<td>1.20</td>
<td>65.47</td>
<td>48.56</td>
<td>38.15</td>
<td>32.85</td>
<td>32.85</td>
</tr>
<tr>
<td>1.40</td>
<td>66.17</td>
<td>49.26</td>
<td>38.84</td>
<td>33.54</td>
<td>33.54</td>
</tr>
<tr>
<td>1.60</td>
<td>66.87</td>
<td>50.06</td>
<td>39.54</td>
<td>34.23</td>
<td>34.23</td>
</tr>
</tbody>
</table>

### Table H.5c)

**FAR 25.121 (CEI) "TRANSITION SEGMENT CLIMB"**

**FAR 25.121 CLIMB GRADIENT (TRANSITION) 6.100C**

<table>
<thead>
<tr>
<th>WING LOADING (LB/FT²)</th>
<th>20.00</th>
<th>40.00</th>
<th>60.00</th>
<th>80.00</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPECT RATIO 1.00</td>
<td>58.27</td>
<td>41.36</td>
<td>33.46</td>
<td>29.51</td>
<td>26.66</td>
</tr>
<tr>
<td>1.20</td>
<td>58.97</td>
<td>42.06</td>
<td>34.16</td>
<td>30.51</td>
<td>27.66</td>
</tr>
<tr>
<td>1.40</td>
<td>59.67</td>
<td>42.76</td>
<td>34.86</td>
<td>31.51</td>
<td>28.66</td>
</tr>
<tr>
<td>1.60</td>
<td>60.37</td>
<td>43.46</td>
<td>35.56</td>
<td>32.51</td>
<td>29.66</td>
</tr>
</tbody>
</table>
## Table H.5d)

**FAR 25.121 (CEI) “EN-ROUTE CLIMB SEGMENT”**

**FAR 25.121 CLIMB GRADIENT (EN-ROUTE)** 1.200G

<table>
<thead>
<tr>
<th>WING LOADING (LB/FT²)</th>
<th>20.0 CC</th>
<th>40.0 CC</th>
<th>60.0 CC</th>
<th>80.00</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPECT RATIO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td>51.83</td>
<td>64.94</td>
<td>53.02</td>
<td>45.62</td>
<td>41.67</td>
</tr>
<tr>
<td>11.00</td>
<td>59.76</td>
<td>47.71</td>
<td>57.44</td>
<td>49.68</td>
<td>42.63</td>
</tr>
<tr>
<td>12.00</td>
<td>63.21</td>
<td>70.26</td>
<td>58.29</td>
<td>51.48</td>
<td>44.71</td>
</tr>
<tr>
<td>13.00</td>
<td>64.81</td>
<td>72.48</td>
<td>58.16</td>
<td>51.48</td>
<td>45.64</td>
</tr>
<tr>
<td>14.00</td>
<td>65.43</td>
<td>74.55</td>
<td>60.87</td>
<td>52.72</td>
<td>47.15</td>
</tr>
</tbody>
</table>

## Table H.5e)

**FAR 25.119 (AEC) “LANDING CLIMB SEGMENT”**

**FAR 25.119 CLIMB GRADIENT (LANDING)** 3.200G

<table>
<thead>
<tr>
<th>WING LOADING (LB/FT²)</th>
<th>20.0 CC</th>
<th>40.0 CC</th>
<th>60.00</th>
<th>80.00</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPECT RATIO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td>54.14</td>
<td>65.48</td>
<td>15.05</td>
<td>13.67</td>
<td>11.69</td>
</tr>
<tr>
<td>11.00</td>
<td>56.55</td>
<td>50.64</td>
<td>12.56</td>
<td>11.67</td>
<td>10.69</td>
</tr>
<tr>
<td>12.00</td>
<td>49.86</td>
<td>50.26</td>
<td>12.56</td>
<td>11.67</td>
<td>10.69</td>
</tr>
<tr>
<td>13.00</td>
<td>28.85</td>
<td>46.44</td>
<td>16.62</td>
<td>14.43</td>
<td>12.50</td>
</tr>
</tbody>
</table>

## Table H.5f)

**FAR 25.121 (CEI) “GC-AROUND OR BALKED LANDING”**

**FAR 25.121 CLIMB GRADIENT (GC-ARCLND)** 2.100G

<table>
<thead>
<tr>
<th>WING LOADING (LB/FT²)</th>
<th>20.0 CC</th>
<th>40.0 CC</th>
<th>60.00</th>
<th>80.00</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPECT RATIO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td>41.53</td>
<td>45.64</td>
<td>24.21</td>
<td>20.57</td>
<td>18.75</td>
</tr>
<tr>
<td>11.00</td>
<td>44.24</td>
<td>44.31</td>
<td>24.17</td>
<td>20.63</td>
<td>19.11</td>
</tr>
<tr>
<td>12.00</td>
<td>44.03</td>
<td>44.31</td>
<td>24.17</td>
<td>20.63</td>
<td>19.11</td>
</tr>
<tr>
<td>13.00</td>
<td>44.07</td>
<td>44.31</td>
<td>24.17</td>
<td>20.63</td>
<td>19.11</td>
</tr>
<tr>
<td>14.00</td>
<td>44.29</td>
<td>44.31</td>
<td>24.17</td>
<td>20.63</td>
<td>19.11</td>
</tr>
<tr>
<td>(W/S) Actual</td>
<td>(W/S) Takeoff</td>
<td>(W/P) Actual</td>
<td>(W/P) Takeoff in Flight</td>
<td>(W/F) Takeoff Static</td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>---------------</td>
<td>--------------</td>
<td>-------------------------</td>
<td>---------------------</td>
<td></td>
</tr>
<tr>
<td>(psf)</td>
<td>(psf)</td>
<td>(lb/ftp)</td>
<td>(lb/ftp)</td>
<td>(lb/ftp)</td>
<td></td>
</tr>
<tr>
<td>200.00</td>
<td>200.00</td>
<td>6.51</td>
<td>6.51</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>60.00</td>
<td>60.00</td>
<td>4.56</td>
<td>4.56</td>
<td>1.31</td>
<td></td>
</tr>
<tr>
<td>80.00</td>
<td>80.00</td>
<td>12.54</td>
<td>12.54</td>
<td>3.76</td>
<td></td>
</tr>
<tr>
<td>100.00</td>
<td>100.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
H.4 Flap Sizing

Using the method of Ref. 2, Ch. 7, it was determined that
the following flap geometry would supply the incremental lift
necessary for take-off and landing (Table H.7).
The design calculations are included.

**TABLE H.7 25 Passenger Flap Geometry**

<table>
<thead>
<tr>
<th>Trailing Edge Flap Geometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c_f/c = 0.15$</td>
</tr>
<tr>
<td>$S_{flap} / S = 0.9$</td>
</tr>
<tr>
<td>$b_f / l = 0.9$</td>
</tr>
<tr>
<td>$\delta_f = 25^\circ$</td>
</tr>
</tbody>
</table>

*ORIGINAL PAGE IS OF POOR QUALITY*
Class I Flap Sizing

From Ch 7, Ref 2

Cl_max = 1.4
C_l_ref = 1.4
Cl_num = 2.2

Using Eqn 7.1

Cl_max = 1.05 Cl_num = 1.47

Using Eqn 7.2 to correct for wing sweep:

Cl_max = Cl_num / cos \( \lambda \)

= 1.47 \( \cos 13^\circ \) = 1.45

Cl_max = 1.45

Using Eqn 7.3 for airfoil sectional Cl_max = 1.5

K_\lambda = 0.95 for \( \lambda \omega = 4 \)

Cl_max = K_\lambda (Cl_react + Cl_max) / 2

Cl_max = 1.42

The results of Eqs 7.2 and 7.3 are less than 1 percent different, therefore to be conservative:

\[ \boxed{\text{Cl_max = 1.43}} \]

The required incremental Cl_max to be generated by flaps:

\[ \Delta \text{Cl_max} = \begin{cases} 1.05 \ (\text{Cl_max}_o - \text{Cl_num}) \\ 0 \ \text{Cl_max}_o = 0 \end{cases} \]

\[ \Delta \text{Cl_max}_L = 1.05 \ (\text{Cl_max}_L - \text{Cl_max}) \]

\[ \Delta \text{Cl_max}_L = 0.84 \]
Using Eqn 7.10,

\[ \Delta C_{\text{max}} = \Delta C_{\text{max}} \left( \frac{5 \text{ft}}{5 \text{ft}} \right) \]

From Eqn 7.9, \( K_N = 0.94 \)

\[ \Delta C_{\text{max}} = 0.79 \left( \frac{5 \text{ft}}{5 \text{ft}} \right) \]

where \( \frac{5 \text{ft}}{5 \text{ft}} = 1.0 \), which requires stall span \( \delta_{\text{flap}} \) over the whole wing.

\[ \Delta C_{\text{max}} = 0.98 \]

Flap flaps were chosen to generate this \( \Delta C_{\text{max}} \).

For \( \Delta C_{\alpha} \) at the flap section, by Eqn 7.11

\[ \Delta C_{\alpha} = \left( \frac{1}{K} \right) \Delta C_{\text{max}} \]

\[ C_{\alpha} = 6.0 \text{ rad}^{-1} \quad (NLF \ \text{airfoil data}) \]

\[ C_{\delta} = 1.25 \]

\[ C_{\delta_{\text{flap}}} = 6.0 \text{ rad}^{-1} \]

by Eqn 7.14

\[ \Delta C_{\alpha} = C_{\alpha_{\text{max}}} \delta_{\delta} \delta_{\text{flap}} \]

for \( \delta_{\text{flap}} = 25^\circ \), \( \delta_{\delta} = 0.34 \)

from Fig. 7.8

\[ \Delta C_{\alpha} = 6.0 \left( 0.34 \right) \left( \frac{25}{57.3} \right) \]

\[ \Delta C_{\alpha} = 0.98 \]

Comparing this with the result of Eqn 7.11, it is seen that the choices for the flaps will generate the required \( \Delta C_{\alpha} \).
H. S. 8-Bar Method for Engineers. Setting.

Ch. 8, Ref. 2.

A T-bar type Emf difference conforming.

Table H.8 presents the results of the experiment.

Average value for $V_H$ and $V_L$ from Table 1.

And Fig. 8 resulted in:

$V_H = 1.08$

$V_L = 1.93$

Similarly for $S_e, S_H$, $S_o, S_L$, $S_r, S_v$ averages were found.

$S_e/S_H = 1.36$

$S_o/S_L = 0.96$

$S_r/S_v = 1.34$

For the 85 bar:

$s = 421.5 + 2$

$c = 6.29 5 +$

$x_H = 31.9 5 +$

$b = 7.1 5 +$

$x_v = 27.1 5 +$

From Eqn. 2.3 Ref. 2

$S_H = \frac{V_H \cdot S_c}{x_H}$

$S_H = 61 5 + 2$.  

From Eqn. 2.4, Ref. 2

$S_v = \frac{V_v \cdot S_b}{x_v}$

$S_v = 56 5 + 2$.  

H.15
For the control surface:
\[ C_n = 2.5 \, ft^2 \]
\[ S_r = 19 \, ft^2 \]
\[ S_p = 22 \, ft^2 \]

**Table I: Geometry for the Configuration**

<table>
<thead>
<tr>
<th>Horizontal Tail</th>
<th>Vertical Tail</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S_H = 61 , ft^2 )</td>
<td>( S_V = 56 , ft^2 )</td>
</tr>
<tr>
<td>( A_H = 3.5 )</td>
<td>( A_V = 1.1 )</td>
</tr>
<tr>
<td>( \lambda_H = 1.65 )</td>
<td>( \lambda_V = 1.9 )</td>
</tr>
<tr>
<td>( \alpha_{CL} = 20^\circ )</td>
<td>( \alpha_{CL} = 45^\circ )</td>
</tr>
<tr>
<td>( \overline{C_H} = )</td>
<td>( \overline{C_V} = )</td>
</tr>
<tr>
<td>( b_H = 14.6 , ft. )</td>
<td>( b_V = 7.9 , ft. )</td>
</tr>
<tr>
<td>( C_T = 6.4 , ft. )</td>
<td>( C_T = 8.0 , ft. )</td>
</tr>
<tr>
<td>( C_e = 4.16 , ft. )</td>
<td>( C_e = 6.4 , ft. )</td>
</tr>
<tr>
<td>( (b/c) = .11 )</td>
<td>( \overline{C_V} = 6.8 , ft. )</td>
</tr>
<tr>
<td>( \Gamma = 0^\circ )</td>
<td>( )</td>
</tr>
<tr>
<td>( \iota = 0^\circ )</td>
<td>( )</td>
</tr>
</tbody>
</table>
From Chap 9 of Ref 2, it was decided to choose a 30" dia. tire by 9" wide. This tire can carry 20,000 lb.

From weight and balance calculations, longitudinal gear placement criteria were met. There is 15° between the ground control point and the aft CG location.

Figure H1 shows that lateral tip-over criteria is met for a 270" wheel base

Original page is of poor quality
For the 25 pay

To satisfy requirements, angle $\psi$ must be $\leq 55^\circ$.
II.7 Stability And Control Calculations

Calculation of required Stability derivatives are
Presented in this section.

Calculation of $C_{l_{aw}}$, H-20
Calculation of $C_{l_{aw}}$, H-20
Calculation of $C_{l_{aw}}$, H-21
Multi-pass Integration, H-22
Calculation of $\Delta C_{A_{ac}}$, H-24
Calculation of $C_{l_{av}}$, H-26
Calculation of $C_{n_{pe}}$, H-27
Calculation of $C_{n_{pe}}$, H-28
Calculation of $C_{n_{pe}}$, H-29
Calculation of $C_{n_{pe}}$, H-30
Engine-out calculation, H-31
25: Page

**C\text{L,w}** **Wing Lift Curve Slope.**

- \( \alpha = 7 \quad \beta = 42.1 \quad ft \quad \ell \)
- \( \lambda_{LE} = 15^\circ = 0.263 \text{ rad} \)
- \( A = 12 \)

From Ref 5, Fig 3.12

For \( A = 12 \)

\[
K = 1 + \left[ \left( 2 \cdot \lambda_{LE} - 2 \cdot \lambda_{C} \right) \right] \left( 1 - 0.153 \lambda_{LE} \right) \frac{1}{100}
\]

\( K = 1.0544 \)

\( \lambda_{C/2} = 11.12^\circ \quad \tan \lambda_{C/2} = 1.965 \)

\( C_{L,w} = 6.0 \text{ rad}^{-1} \) **(NLF Airfoil data)**

\( \beta = \sqrt{1 - \lambda_{C}^2} = 0.7141 \)

\( K = C_{L,2}/2\pi/\ell = 16.420 \)

\[
C_{L,w} = \frac{27A}{\left( 2 + \sqrt{\frac{\lambda_{C}^2}{\ell}} \left( 1 + \frac{\tan^2 \lambda_{C/2}}{\ell^2} \right) \right) \ell}
\]

\[ C_{L,w} = 4.71 \text{ rad}^{-1} \]

**C\text{L,H}** **Horizontal tail lift curve slope.**

- \( \lambda_{LE} = 20^\circ \quad \lambda_{C/2} = 14.9^\circ \quad \tan \lambda_{C/2} = 1.2699 \)
- \( S = 69 \text{ ft}^2 \quad A = 4 \quad K = 1.0673 \)

\[ C_{L,H} = 3.41 \text{ rad}^{-1} \]

using Fig 3.12 of Ref 5.
Calculation of $\frac{dE}{dx}$

Using Ref 5.

From Figure 2.26

$M = \frac{dE}{dx}$

$1 - \frac{dE}{dx} = 0.78$
MULTIROP'S INTEGRATION (125 PASSOWECZ)

Method: Ref. 5 Section 3.4.6

$C_f = 82''$  \hspace{1cm} $S = 420.9 \text{ ft}^2$

$L_H = 4/15''$ \hspace{1cm} $E = 6.2 \text{ ft}$

$\frac{dE}{dH} = 0.220$

$C_{L_{BD}} = C_{L_{B}} = 4.712 \text{ rad}^{-1}$

$\Delta X_{A_{B}} = \frac{-dM}{q SE C_{L_{BD}}}$ \hspace{1cm} \text{Eqn 381 Ref 5}$

$-\frac{dM}{dx} = \frac{q}{36.5} \sum \omega_i (v_i \frac{dx}{dx})_i dx$ \hspace{1cm} \text{Eqn 3.28a Ref 5}$
\[ \frac{dM}{dx} = 3 \sqrt{5} \times (27.43) = 75.2 \frac{g}{s} \]

\[ \Delta \bar{X}_{ac}_{B} = - \frac{\frac{dM}{dx}}{\frac{8}{g} \times \sum \bar{X}_{ac} \times \Delta X} = - \frac{75.2 \frac{g}{s}}{8 \times (420.9 \times 0.0002)} = -0.34 \]

\[ \bar{X}_{acwB} = \bar{X}_{acw} + \Delta \bar{X}_{ac}_{B} = 0.25 - 0.34 \]

\[ \bar{X}_{acwB} = -0.09 \]
Calculation of $\bar{X}_{acA}$

$\bar{X}_{ac A} = -1.09$

$C_{L_{ac A}} = 3.41 \text{ rad}^{-1}$

$d\bar{X}_{ac A} = 0.30$

$C_{L_{ac A}} = 4.71 \text{ rad}^{-1}$

$\bar{X}_{ac A} = \bar{X}_{ac W_{B}} + \left[ C_{L_{ac A}} (1 - d\bar{X}_{ac A}) \bar{X}_{ac A} \right] / C_{L_{ac W_{B}}}$

$1 + \left[ C_{L_{ac A}} (1 - d\bar{X}_{ac A}) \bar{X}_{ac A} \right] / C_{L_{ac W_{B}}}$

This is Eqn 11.1 of Ref 2

$\bar{X}_{ac A} = 0.45$

Writing $\bar{X}_{ac A}$ in terms of $SH/5$ results in:

$\bar{X}_{ac A} = -0.04 + 0.0045 \cdot (SH/5)$

<table>
<thead>
<tr>
<th>$SH$</th>
<th>$SH/5$</th>
<th>$\bar{X}_{ac A}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.048</td>
<td>0.09</td>
</tr>
<tr>
<td>40</td>
<td>0.095</td>
<td>0.14</td>
</tr>
<tr>
<td>60</td>
<td>0.143</td>
<td>0.39</td>
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<tr>
<td>80</td>
<td>0.190</td>
<td>0.53</td>
</tr>
<tr>
<td>100</td>
<td>0.238</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Plotted in Fig H.2

$X_{cg}$ shift due to changing tail area

$\bar{W_{H}} / SH = 2.81 \text{ lb/ft}^2$

<table>
<thead>
<tr>
<th>$SH$</th>
<th>$W_{H}$</th>
<th>$W_{exp}$</th>
<th>$X_{cg}$</th>
<th>$\bar{X}_{cg}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>140.6</td>
<td>520.2</td>
<td>422</td>
<td>0.36</td>
</tr>
<tr>
<td>60</td>
<td>163.7</td>
<td>548.3</td>
<td>423</td>
<td>0.37</td>
</tr>
<tr>
<td>70</td>
<td>196.9</td>
<td>576.4</td>
<td>423</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Plotted in Fig H.2
Figure H.2
Longitudinal X-Plot
25 Passenger Commuter

UNIVERSITY OF KANSAS
Calculation of $C_{L_{\alpha},V}$

$S = \ldots$

$C_{L_{\alpha},V}$ was calculated using Fig 3.12 of Ref 5.

The vertical tail geometry of Table H.5 was used as input data.

The result was,

$C_{L_{\alpha},V} = 1.46 \text{ rad}^{-1}$
Cn_p Calculations

\[ C_{n_{le}} = -57.3 K_v K_{f_e} \frac{S_{b_e}}{5} \frac{l_e}{b} (\text{rad}^{-1}) \]

\[ t_0 = 823 \text{ in} = 69.6 \text{ ft} \]

\[ k_m = 423.2 \text{ in} = 35.2 \text{ ft} \]

\[ w_5 = h = 96.6 \text{ in} = 8.05 \text{ ft} \]

\[ S_{b_e} = 62938.5 \text{ in}^2 = 4371.1 \text{ ft}^2 \]

\[ \frac{h_0}{4} = 205.8 \text{ in} \implies h_0 = 8.05 \text{ ft} \]

\[ \frac{3h_0}{4} = 617.3 \text{ in} \implies h_2 = 5.83 \text{ ft} \]

\[ \frac{l_{e_0}}{l_e} = 0.51 \]

\[ \frac{l_0^2}{S_{b_e}} = 10.8 \]

\[ \sqrt{\frac{h_0}{h_2}} = 1.2 \]

\[ \frac{s}{h_0} = 1 \]

\[ K_v = 0.0015 \]

\[ \mu = 3.106 \times 10^{-7} \text{ sl}^{-2} \text{ ft}^{-2} \]

\[ \rho = 0.8892 \times 10^{-3} \text{ sl}^{-2} \text{ ft}^{-3} \]

\[ V = 696.3 \text{ ft}^2/\text{sec} \]

\[ K_N = \frac{\rho V l_0}{\mu} = 136.8 \times 10^6 \]

\[ K_{R_N} = 2.005 \]
Calculation for engine-out flight of rubber deiceion.

From Ref 6,

\[
C_{\text{yr}} = -1.014 \frac{5v}{5}
\]

\[
C_{\text{ns}} = 1.014 \frac{5v}{b}
\]

\[
C_{\text{ns}} = 0.428 \frac{5v}{s}
\]

Where:

\[x_v = 30 \text{ ft}\]

\[b = 71.1 \text{ ft}\]

\[s = 420.9 \text{ ft}^2\]

\[
C_{\text{ns}} = 0.001 \frac{5v}{s}
\]

From Eqn 11.18, Ref 2, Section 11.3,

\[
S_r = \frac{(N_d + N_{\text{cei}})}{gmc} s_b C_{\text{ns}}
\]

\[y_{T_0} = 7.5 \text{ ft}\]

\[P_{\text{TO,1}} = 4210 \text{ SHP - One Engine}\]

\[
T_{\text{TO}} = \frac{550 (\text{SHP}) n_p}{\sqrt{V_{\text{TO}}}}
\]

\[V_{\text{TO}} = 191 \text{ ft/sec}\]

\[n_p = 0.80\]

\[T_{\text{TO}} = 9698 \text{ lbs}\]

\[N_{\text{cl}} = y_T T_{\text{TO}} = 72735 \text{ ft lbs}\]
\[ C_{n_B} = -57.3 \ K_n \ K_{RL} \ \frac{S_{BS}}{S} \ \frac{q_B}{b} \]

\[ C_{n_B} = -1.17 \]

**Calculation of \( C_{n_B} \)**

\[ C_{n_B} = C_{n_B e} + C_{n_B v} \]

\[ C_{n_B} = -1.171 + 0.0015 \ \text{Sv} \]

\[ C_{n_B e} = \frac{C_{n_B} \text{ (deg)} - C_{n_B}}{\text{deg}} \]

<table>
<thead>
<tr>
<th>( S_{n} )</th>
<th>( C_{n_B} ) (deg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-0.0030</td>
</tr>
<tr>
<td>50</td>
<td>-0.0017</td>
</tr>
<tr>
<td>100</td>
<td>-0.0004</td>
</tr>
<tr>
<td>150</td>
<td>0.0009</td>
</tr>
</tbody>
</table>

\[ S_{n_{req}} = 160 \ \text{ft}^2 \] to satisfy lateral directional requirement for \( C_{n_B} \)

A directional X-plot is presented in Figure II.3

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Figure 73: Directional X-Plot

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\[W_0 = 0.25 W_{c,exit} = 1818.3\]

\[V_{mc} = 1.2 V_{sc}\]
\[C_{max} = 2.1\]

\[V_{sc} = 141.5 \text{ ft/\text{sec}}\]
\[V_{mc} = 170 \text{ ft/\text{sec}}\]

\[\frac{q_{mc}}{V_{mc}} = 3.44 \text{ psf}\]

\[S_2 = \frac{0.0883}{C_{max}} = \frac{88.32}{S_v}\]

**Requires 200 ft^2 of vertical tail**

For \[y_T = 6.5 \text{ ft}\]

\[S_0 = \frac{0.0765}{C_{max}} = \frac{76.54}{S_v}\]

\[S_v = 170 \text{ ft}^2 \text{ will need}\]

\[S_R = 25.8\]

\[C = 2\]
Resized Empennage From Stability and Control

**Horizontal Tail**

- \( S_H = 69 \text{ ft}^2 \)
- \( A_H = 4 \)
- \( b_H = 16.6 \text{ ft} \)
- \( \lambda_H = 0.7 \)
- \( C_{\text{rH}} = 4.9 \text{ ft} \)
- \( \Lambda_{\text{LE}} = 20^\circ \)
- \( Z_H = 4.2 \text{ ft} \)

**Vertical Tail**

- \( S_V = 170 \text{ ft}^2 \)
- \( A_V = 1.15 \)
- \( b_V = 14 \text{ ft} \)
- \( \lambda_V = 0.3 \)
- \( C_{\text{rV}} = 18.7 \text{ ft} \)
- \( C_{\text{rT}} = 5.6 \text{ ft} \)
- \( \Lambda_{\text{LE}} = 54^\circ \)
- \( Z_V = 12.3 \text{ ft} \)
4.8 Calculation of Class II Drag Polars

This section computes the airplane's wetted area, and estimates skin friction drag. Class II Drag Polars are constructed and compared with the polars computed from the performance data. Table #1 contains a wetted area breakdown.
List of components that contribute to wetted area:

- Fuselage
- Empennage
- Wing

\[ \text{Swe} = \text{S}_{\text{Exp}} - \text{S}_{\text{Fuselage}} \]

\[ \text{Swe} = 2.5 \left( 1 + \frac{1}{\lambda} \right) \left[ \frac{1 + 1.25 \left( \frac{c}{L} \right)}{1 + \lambda} \right] \]

\[ \zeta = 1.0, \quad \lambda = 1.0, \quad \left( \frac{c}{L} \right) = 1.25 \]

\[ \text{Swe} = 421 - \left( \frac{1}{1.5(0.25)} \right) \left( 1 + 1.25(1.25) \right) - \frac{1}{1.44} \]

\[ \text{Swe} = 346 \text{ ft}^2 \]

\[ \sqrt{\text{Swe}} = 71.7 \text{ ft}^2 \]

3. Horizontal Tail

\[ \text{Swe} = 2(69) \left( 1 + 1.25(1.11) \right) \]

\[ \text{Swe} = 2(69) \left( 1 + 1.25(1.11) \right) \]

\[ \text{Swe} = 142 \text{ ft}^2 \]

Vertical Tail

\[ S_v = 170 \text{ ft}^2, \quad \lambda = 1.3, \quad \zeta = 1.0, \quad \left( \frac{c}{L} \right) = 1.11 \]

\[ \text{Swe} = 2(170) \left( 1 + 1.25(1.11) \right) \]

\[ \text{Swe} = 349 \text{ ft}^2 \]
Fuselage

\[ Swet_{fus} = \pi D_f D_5 \left( 1 - \frac{2}{\lambda_5} \right)^{2/3} \left( 1 + \frac{1}{\lambda_5^2} \right) \]

\[ \lambda_5 = \frac{D_5}{D_5} = 3.5 \]

\[ D_f = 9.3 \text{ in} \]

\[ Swet_{fus} = \pi \left( 9.6 \right) \left( 9.3 \right)^{2/3} \left( 1 - \frac{2}{3.5} \right) \left( 1 + \frac{1}{(3.5)^2} \right) / 144 \]

\[ Swet_{fus} = 14.7 \text{ ft}^2 \]

Nacelle

\[ Swet = \pi \rho_{nac} D_{nac} \]

\[ Swet = \pi \left( 102.5 \right) \left( 2.2 \right) \]

\[ Swet = 92 \text{ ft}^2 \]

Total = 190 ft^2

Pylons

\[ Swet = 2 \cdot \text{Seqf} \left[ 1 + \frac{2.5 \left( 4/c \right)_r \left( 1 + 2 \lambda \right)}{(1+\lambda)} \right] \]

\[ \lambda = 1 \quad \rho = 1.0 \quad \left( 4/c \right)_r = 0.11 \]

\[ Swet = 2 \left( 70.8 \right) \left[ 1 + 2.5 \left( 0.11 \right) \right] \]

\[ Swet = 80 \text{ ft}^2 \]
TABLE H.9 Wetted Area of 25 Pay Airplane Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Wetted Area (ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing</td>
<td>71.7</td>
</tr>
<tr>
<td>H-Tail</td>
<td>14.2</td>
</tr>
<tr>
<td>V-Tail</td>
<td>3.49</td>
</tr>
<tr>
<td>Fuselage</td>
<td>18.0</td>
</tr>
<tr>
<td>Flaps/人参is</td>
<td>80</td>
</tr>
</tbody>
</table>
| Total                | 29.39             | 2 ft²

From Fig. A. 1 of Reference 1.1

\[ S = 7.2 \text{ ft}^2 \quad \alpha \quad C_D = 0.0275 \]

\[ C_{D0} = \frac{S}{S} = 0.171 \]

for compressibility effects.

\[ C_{D0} = 0.173 \]

Take-off \( C_{D0} \) increment:

- 0.015 for gear

Landing \( C_{D0} \) increment:

- 0.015 for gear
- 0.075 for flaps

Oswald's efficiency factor

Take-off \( e = 0.80 \)

Cruise \( e = 0.85 \)

Landing \( e = 0.80 \)
**Drag Polar**

\[ A = 1.2 \]

\[ C_D = C_{D0} + C_L^2 / \pi A_2 \]

**Take-off**

\[ C_D = 1.0321 + 1.0322 C_L^2 \]

**Cruise**

\[ C_D = 1.0173 + 1.0312 C_L^2 \]

**Landing**

\[ C_D = 1.0711 + 1.0332 C_L^2 \]

For Cruise, \( C_{L_{cr}} = 1.30 \quad (L/D)_{cr} = 14.92 \)

---

From initial weight sizing on \( (L/D)_{cr} = 16 \) was assumed and \( \Delta W_{TD} / \Delta (L/D) = -500.7 \text{ lb.} \) was calculated.

\[ \Delta L/D = \text{Class I} \ (L/D) - \text{Initial} \ (L/D) \]

\[ = 14.92 - 16 = -1.08 \]

Therefore:

\[ \Delta W_{TD} = -W_{TD} / \Delta (L/D) = (-500.7 \text{ lb}) \cdot (-1.08) \]

\[ \Delta W_{TD} = 540.8 \text{ lb increase.} \]

\[ W_{TD_{new}} = 2104.6 + 541 \text{ lb} = 21587 \text{ lb}. \]

This represents a 2,690 lb change in take-off weight. This change is so small that resizing of the airplane is not required. \( \#37 \)
Appendix I

Engineering Calculations For The 36 Passenger Commuter
Table of Contents

I.1 Introduction
I.2 Preliminary Weight Sizing
I.3 Preliminary Performance Sizing
I.4 Class I Flap Sizing
I.5 Class II Empennage Sizing
I.6 Landing Gear Criterion
I.7 Stability and Control Calculations
I.8 Class II Drag Polars

ORIGINAL PAGE IS OF POOR QUALITY
I. Introduction

The purpose of this Appendix is to present the preliminary sizing and Class I design calculations. Methods used were taken from References 1, 2, 5, and 6. These results are for stability and control design considerations.

Section I.2 contains preliminary weight sizing calculations. These results are from XWTOG, a computer program available at Kansas University.

Section I.3 contains preliminary performance results from XPFRM.

Section I.4 contains Class I flap sizing calculations.

Section I.5 contains Class I component sizing (V-bar method).

Section I.6 contains landing gear design criteria.

Section I.7 contains stability and control calculations.

Section I.8 contains the tested area calculations and the Class I drag polar.
I.2 Final Weight Sizing

Using XEWTOG, a weight sizing program which follows the method in Ch 2. of Reference 1., the following weights and take-off weight sensitivities for the 36 passenger airplanes.

See Table I.1.

The design assumptions used in the weight sizing are:

\[(L/D) C_2 = 16\]
\[C_p = 0.4 \text{ LBS/HP/HR}\]
\[u_p = 0.85\]
\[V_{CR} = 442 \text{ KTS}\]
## Table I.1 Initial Weight Sensitivity Results

Weight Estimation for a Regional Propeller Driven Aircraft

<table>
<thead>
<tr>
<th>Phase W/W CJ or CP NP</th>
<th>L/C</th>
<th>ALTC</th>
<th>FL</th>
<th>MCR OP V</th>
<th>E OP E</th>
<th>FLDCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.920</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>0.925</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>0.920</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>7</td>
<td>0.920</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Regression coefficients are $a = 0.3939$ and $e = 0.5647$

The mission fuel fraction without reserves is 0.357

The gross take off weight is 11195 pounds.

The empty weight is 17295 pounds.

The weight of fuel is 5620 pounds.

Empty weight reduction due to composites: 5.0 per cent

**SENSITIVITY ANALYSIS BEGINS HERE**

Growth factor due to payload weight is 4.4

The take-off weight to empty weight sensitivity is 1.7

### Choice Number... CRUISE

- SPEC (LB/LB/HR): 5
- SPEC (LB/HP/HR): 0.44
- PROP EFFICIENCY: 0.68
- VELOCITY (KNOTS): 0.0
- RANGE (NT. MILES): 1100.0
- ENDURANCE (HRS): 4.5

The sensitivity of gross take-off weight to the following parameters is now given as the partial derivative of the gross take-off weight to the indicated parameter.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>DWT/DCJ (LB/LB/LB/HR)</td>
<td>0.0</td>
</tr>
<tr>
<td>DWT/DCP (LB/LB/HP/HR)</td>
<td>30976.4</td>
</tr>
<tr>
<td>DWT/DNP (Pounds)</td>
<td>-14577.1</td>
</tr>
<tr>
<td>DWT/DCL/D (Pounds)</td>
<td>-774.4</td>
</tr>
<tr>
<td>DWT/DV (LB/KNOT)</td>
<td>0.9</td>
</tr>
<tr>
<td>DWT/DR (LB/NT MILE)</td>
<td>11.3</td>
</tr>
<tr>
<td>DWT/DE (LB/HR)</td>
<td>0.0</td>
</tr>
</tbody>
</table>
1.3 Initial Performance Levels

The results from XPRFRM, a performance rating program, are presented in this section. The methods used are in Ch. 3 of Reference 2. See Tables 1.3 through 1.6.

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### Table I.2

**FAR 25 CERTIFICATION CATEGORY**

<table>
<thead>
<tr>
<th>REGIONAL TURBO-PROP</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROPELLER DRIVEN</td>
</tr>
</tbody>
</table>

**INPUT DATA**

<table>
<thead>
<tr>
<th>ALTITUDE (FEET)</th>
<th>TAKE-OFF DISTANCE &lt;STC&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500</td>
<td>260.4 (FEET)</td>
</tr>
<tr>
<td>2000</td>
<td>260.4 (FEET)</td>
</tr>
<tr>
<td>2500</td>
<td>260.4 (FEET)</td>
</tr>
<tr>
<td>3000</td>
<td>260.4 (FEET)</td>
</tr>
</tbody>
</table>

**OUTPUT DATA**

<table>
<thead>
<tr>
<th>MAXIMUM LIFT COEFFICIENT</th>
<th>MAXIMUM TAKE-OFF LIFT COEFFICIENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4</td>
<td>2.0</td>
</tr>
</tbody>
</table>

**TABLE OF POWER LOADINGS**

<table>
<thead>
<tr>
<th>W/S</th>
<th>CLMAX-T0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>1.40</td>
</tr>
<tr>
<td>2.00</td>
<td>1.60</td>
</tr>
<tr>
<td>3.00</td>
<td>2.30</td>
</tr>
<tr>
<td>5.00</td>
<td>2.80</td>
</tr>
<tr>
<td>10.00</td>
<td>3.50</td>
</tr>
</tbody>
</table>

### Table I.3

**LANDING FIELD LENGTH SPECIFICATION**

<table>
<thead>
<tr>
<th>REGIONAL TURBO-PROP</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAR 25 CERTIFICATION CATEGORY</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GROSS TAKE-OFF WEIGHT (LBS)</th>
<th>31395.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>LANDING TO TAKE-OFF WEIGHT RATION</td>
<td>1.000</td>
</tr>
<tr>
<td>ALTITUDE (FEET)</td>
<td>0.0</td>
</tr>
<tr>
<td>DENSITY</td>
<td>0.02376</td>
</tr>
<tr>
<td>LANDING APPROACH SPEED (KTS)</td>
<td>350.0</td>
</tr>
<tr>
<td>LANDING FIELD LENGTH (FEET)</td>
<td>3500.0</td>
</tr>
</tbody>
</table>

(W/S) TO 23.40 CLMAX(LAND)

**MAXIMUM TAKE-OFF WING LOADINGS**

<table>
<thead>
<tr>
<th>TO MEET LANDING DISTANCE REQUIREMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLMAX</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(LAND)</th>
<th>(TAKE-OFF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(LE/FT=2)</td>
<td>(LE/FT=2)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ORIGINAL PAGE IS</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR POOR QUALITY</td>
</tr>
</tbody>
</table>
# DRAG POLAR EQUATIONS

## PROBLEM DESCRIPTION

### INPUT DATA

- Maximum Take-Off Weight (Clean): 31395.2 LBS
- Maximum Landing Weight (Clean): 50000.0 LBS
- Skid Friction Coefficient: 0.14
- Drag Pole Length: 1.81

### CALCULATED DATA

The complete set of drag polar is:

1. **Low-Speed (Clean):**
   - \( C_D = 0.0214 + 0.332 \cdot C_{L}^2 \)
   - \( L/D_{max} = 19.2^\circ \)

2. **Take-Off (Landing Gear Up):**
   - \( C_D = 0.0412 + 0.332 \cdot C_{L}^2 \)
   - \( L/D_{max} = 13.47 \)

3. **Take-Off (Landing Gear Down):**
   - \( C_D = 0.0562 + 0.332 \cdot C_{L}^2 \)
   - \( L/D_{max} = 11.55 \)

4. **Landing (Landing Gear Up):**
   - \( C_D = 0.0974 + 0.332 \cdot C_{L}^2 \)
   - \( L/D_{max} = 9.62 \)

5. **Landing (Landing Gear Down):**
   - \( C_D = 0.0965 + 0.332 \cdot C_{L}^2 \)
   - \( L/D_{max} = 8.84 \)

---

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### Table I.5 (a)

**FAR 25.111 (CEI) "INITIAL CLIMB SEGMENT"**

**FAR 25.111 CLIMB GRADIENT (INITIAL SEGMENT) 1.2000C**

<table>
<thead>
<tr>
<th>WING LOADING (LBS/FT²)</th>
<th>20.0C</th>
<th>40.0C</th>
<th>60.0C</th>
<th>80.0C</th>
<th>100.0C</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPECT RATIO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>64.94</td>
<td>55.63</td>
<td>45.70</td>
<td>42.54</td>
<td>37.71</td>
</tr>
<tr>
<td>1.10</td>
<td>64.74</td>
<td>55.47</td>
<td>45.52</td>
<td>42.47</td>
<td>37.69</td>
</tr>
<tr>
<td>1.20</td>
<td>64.54</td>
<td>55.31</td>
<td>45.32</td>
<td>42.40</td>
<td>37.67</td>
</tr>
<tr>
<td>1.40</td>
<td>64.05</td>
<td>54.76</td>
<td>44.87</td>
<td>41.66</td>
<td>36.72</td>
</tr>
</tbody>
</table>

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### Table I.5 (b)

**FAR 25.121 (CEI) "SECOND SEGMENT CLIMB"**

**FAR 25.121 CLIMB GRADIENT (SECOND SEGMENT) 2.4000C**

<table>
<thead>
<tr>
<th>WING LOADING (LBS/FT²)</th>
<th>20.0C</th>
<th>40.0C</th>
<th>60.0C</th>
<th>80.0C</th>
<th>100.0C</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPECT RATIO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>75.35</td>
<td>66.92</td>
<td>56.69</td>
<td>47.50</td>
<td>37.42</td>
</tr>
<tr>
<td>1.10</td>
<td>75.27</td>
<td>66.77</td>
<td>56.53</td>
<td>47.33</td>
<td>37.24</td>
</tr>
<tr>
<td>1.20</td>
<td>75.02</td>
<td>66.46</td>
<td>56.20</td>
<td>47.05</td>
<td>37.05</td>
</tr>
<tr>
<td>1.40</td>
<td>74.09</td>
<td>65.63</td>
<td>55.31</td>
<td>46.02</td>
<td>36.18</td>
</tr>
</tbody>
</table>

### Table I.5 (c)

**FAR 25.121 (CEI) "TRANSITION SEGMENT CLIMB"**

**FAR 25.121 CLIMB GRADIENT (TRANSITION) 0.1000C**

<table>
<thead>
<tr>
<th>WING LOADING (LBS/FT²)</th>
<th>20.0C</th>
<th>40.0C</th>
<th>60.0C</th>
<th>80.0C</th>
<th>100.0C</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPECT RATIO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>76.06</td>
<td>67.64</td>
<td>57.41</td>
<td>48.43</td>
<td>39.42</td>
</tr>
<tr>
<td>1.10</td>
<td>75.84</td>
<td>67.42</td>
<td>57.22</td>
<td>48.24</td>
<td>39.24</td>
</tr>
<tr>
<td>1.20</td>
<td>75.62</td>
<td>67.20</td>
<td>57.02</td>
<td>48.04</td>
<td>39.06</td>
</tr>
<tr>
<td>1.40</td>
<td>74.70</td>
<td>66.37</td>
<td>56.17</td>
<td>47.15</td>
<td>38.27</td>
</tr>
</tbody>
</table>
### Table 1.5d)

**FAR 25.121 (CFR) “EN-ROUTE CLIMB SEGMENT”**

**FAR 25.121 CLIMB GRADIENT (EN-ROUTE)**

<table>
<thead>
<tr>
<th>Wing Loading (Lb/ft²)</th>
<th>20.00</th>
<th>40.00</th>
<th>60.00</th>
<th>80.00</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 1.5e)

**FAR 25.119 (ACO) “LANDING CLIMB SEGMENT”**

**FAR 25.119 CLIMB GRADIENT (LANDING)**

<table>
<thead>
<tr>
<th>Wing Loading (Lb/ft²)</th>
<th>20.00</th>
<th>40.00</th>
<th>60.00</th>
<th>80.00</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.00</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>11.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14.00</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

### Table 1.5f)

**FAR 25.121 (OEI) “GO-AROUND OR BALKED LANDING”**

**FAR 25.121 CLIMB GRADIENT (GO-AROUND)**

<table>
<thead>
<tr>
<th>Wing Loading (Lb/ft²)</th>
<th>20.00</th>
<th>40.00</th>
<th>60.00</th>
<th>80.00</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Original page is of poor quality**
<table>
<thead>
<tr>
<th>(h/s)</th>
<th>(h/s)</th>
<th>(w/p)</th>
<th>(h/f)</th>
<th>(w/p)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(psf)</td>
<td>(psf)</td>
<td>(lb/ft)</td>
<td>(lb/ft)</td>
<td>(lb/ft)</td>
</tr>
<tr>
<td>15.50</td>
<td>20.40</td>
<td>1.85</td>
<td>2.00</td>
<td>1.00</td>
</tr>
<tr>
<td>15.50</td>
<td>20.40</td>
<td>1.85</td>
<td>2.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>73.90</td>
<td>83.00</td>
<td>7.50</td>
<td>8.10</td>
<td>5.00</td>
</tr>
<tr>
<td>72.37</td>
<td>100.00</td>
<td>7.27</td>
<td>10.31</td>
<td>5.37</td>
</tr>
</tbody>
</table>

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I.4 Flap Setting

Using a method in Ref. 2, Ch. 7, it was determined that the following flap geometry would supply the incremental lift necessary for take-off and landing. See Table I.7. The design calculations follow.

Table I.7 36 Pax Flap Geometry

<table>
<thead>
<tr>
<th>Training Edge Powered Flaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>c/b = 0.25</td>
</tr>
<tr>
<td>Sw = 1.5  ( b_f / b = 0.9 )</td>
</tr>
<tr>
<td>( \theta_f = 30^\circ )</td>
</tr>
</tbody>
</table>

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CLASS II FLAP SIZING

From CH 7, Ref 2.

\[ C_{\text{max}} = 1.4 \]
\[ C_{\text{max} + 0} = 1.4 \]
\[ C_{\text{max} + 2} = 3.0 \]

Using EQU 7.1

\[ C_{\text{runner}} = 1.05 C_{\text{max}} = 1.47 \]

Using EQU 7.2 to correct for angle sweep:

\[ C_{\text{runner}} = C_{\text{runner} + 0.5} \cos \frac{\alpha}{2} = 1.47 \cos 13^\circ \]
\[ C_{\text{runner}} = 1.43 \]

Using EQU 7.3 using FOR AR-foil

SECTION A: \[ C_{\text{runner}} = 1.5 \]

\[ K_a = 0.95 \text{ for } \alpha = 0.4 \]

\[ C_{\text{runner}} = K_a \left( \frac{C_{\text{runner} + 0.5}}{2} \right) \]
\[ C_{\text{runner}} = 1.42 \]

EQU 7.2 and 7.3 results agree, THEREFORE TO BE CONSIDERED.
Incremental $C_{\text{max}}$ to be generated by the flaps:

- Take-off: $\Delta C_{\text{max}, \text{to}} = 1.05 (C_{\text{max}, \text{to}} - C_{\text{max}})$
- Landing: $\Delta C_{\text{max}, \text{ld}} = 1.05 (C_{\text{max}, \text{ld}} - C_{\text{max}})$
- $\Delta C_{\text{max}, \text{to}} = 0$
- $\Delta C_{\text{max}, \text{ld}} = 1.68$

Using Eqn 7.8

$$\Delta C_{\text{max}} = \Delta C_{\text{max}, \text{to}} (S/\text{Surf}) K_\lambda$$

From Eqn 7.9

$$K_\lambda = 0.906$$

$$\Delta C_{\text{max}} = 1.52 \left( \frac{S}{\text{Surf}} \right)$$

For an $\frac{S}{\text{Surf}} = 0.9$ which requires full span flaps over the wetted wing.

$$\Delta C_{\text{max}} = 1.69$$

Four flaps are necessary to generate such a high $\Delta C_{\text{max}}$. 

J. W.
For 

\[ \Delta C_e \text{ of the flap section} \]

\[ \text{Eqn 7.11} \]

\[ \Delta C_e = \left( \frac{1}{K} \right) C_{e_{\text{max}}} \]

\[ K = 0.98 \text{ taken from Figure 7.4} \]

\[ \Delta C_e = 1.72 \]

Using \text{Eqn 7.17 for Fowler Flaps}

\[ C_{e_{\text{ref}}} = C_{e_0} \left( 1 + C_f/c \right) \]

\[ C_{e_0} = 6.0 \text{ rad}^{-1} \text{ (NLF Airfoil Data)} \]

\[ C_f/c = 0.25 \]

\[ C_{e_{\text{ref}}} = 7.5 \text{ rad}^{-1} \]

Using \text{Eqn 7.14}

\[ \Delta C_e = C_{e_{\text{ref}}} \Delta \delta \]

For \[ \delta_f = 30^\circ \], \[ \Delta \delta_f = 0.15 \]

From Figure 7.8

\[ \Delta C_e = 7.5 \times 0.15 \times 30 \]

\[ \Delta C_e = 1.77 \]

Comparing with Eqn 7.11, it is seen that the choices for the flaps will generate the required \( \Delta C_e \).
IS V - BAR Method for Empannace Size

Ref 2, Cu 8.

A T-TAIL TYPE EMPIEENACE, CONVENTIONAL.

Table I & II contain the geometry of the empannace.

Taking an average value for \( \overline{v_H} \) \( \overline{v_N} \) from

Tables 8.6a and 8.6b. Results:

\[
\overline{v_H} = 1.08
\]

\[
\overline{v_N} = 0.83
\]

Similarly for \( S_e/S_u \), \( S_o/S \), \( S_r/S_n \)

Averages were found:

\[
\frac{S_e}{S_u} = 0.36
\]

\[
\frac{S_o}{S} = 0.06
\]

\[
\frac{S}{S_r} = 0.34
\]

For the 36 Pak

\[
S = 44.9 \text{ ft}^2
\]

\[
\overline{e} = 6.5 \text{ ft}
\]

\[
x_H = 4.6 \text{ ft}
\]

\[
b = 73.4
\]

\[
x_N = 35 \text{ ft}
\]

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From EEC 8.3 Ref 2.
\[ S_H = \frac{V_H \cdot S_E}{X_H} \]
\[ \therefore S_H = 69 \text{ ft}^2 \]

From EEC 8.4 Ref 2.
\[ S_V = \frac{V_V \cdot S_E}{X_V} \]
\[ \therefore S_V = 78 \text{ ft}^2 \]

For the Control Surfaces:
\[ S_a = 27 \text{ ft}^2 \]
\[ S_r = 26.5 \text{ ft}^2 \]
\[ S_c = 25 \text{ ft}^2 \]

**TABLE 1.8**

**GEOMETRIC DECISIONS FOR THE EMPIRE ACE**

<table>
<thead>
<tr>
<th>Horizontal Tail</th>
<th>Vertical Tail</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S_H = 69 \text{ ft}^2 )</td>
<td>( S_V = 78 \text{ ft}^2 )</td>
</tr>
<tr>
<td>( A_H = 4 )</td>
<td>( A_V = 1.3 )</td>
</tr>
<tr>
<td>( \lambda_H = .7 )</td>
<td>( \lambda_V = .5 )</td>
</tr>
<tr>
<td>( \alpha_{4.5} = 20^\circ )</td>
<td>( \alpha_{4.5} = 45^\circ )</td>
</tr>
<tr>
<td>( T_H = 4.2 \text{ ft} )</td>
<td>( (\xi/c)_V = .11 )</td>
</tr>
<tr>
<td>( b_H = 16.6 \text{ ft} )</td>
<td>( r = 70^\circ )</td>
</tr>
<tr>
<td>( C_p = 0.88^\prime )</td>
<td>( \theta = 10^\circ )</td>
</tr>
<tr>
<td>( C_t = .51^\prime )</td>
<td>( b_r = 10.1 \text{ ft} )</td>
</tr>
<tr>
<td>( (\xi/c)_H = .11 )</td>
<td>( C_r = 124^\prime )</td>
</tr>
<tr>
<td>( \eta = 0^\circ )</td>
<td>( C_t = 62^\prime )</td>
</tr>
<tr>
<td>( \gamma = 10^\circ )</td>
<td>( \psi = 18.64 \text{ ft} )</td>
</tr>
</tbody>
</table>
1.6 Class I Landing Gear Design

From Ch 9. in Ref 2, it was decided to choose a 30” dia tire 9” wide. This tire can carry 2000 lbs. From weight and balance calculation longitudinal gear placement criterion were met. There is 15° between ground contact point and aft C.G.

Figure 1.1. shows that lateral tip-over criterion is met for a 180” wheel base.
LATERAL TIP OVER CRITERIA TEST
FOR THE 36 PAK.

To meet requirement angle $\gamma$ must be $\leq 55^\circ$.
I.7 Stability and Control Calculations

Calculation of Required Stability Derivatives Are Presented in This Section.

Calculation of $C_{L_{MW}}$, Page I.21
Calculation of $C_{L_{LH}}$, Page I.22
Calculation of $C_{L_{DH}}$, Page I.23
Multhop's Integration, Page I.24
Calculation of $C_{N_{AC}}$, Page I.26
Calculation of $C_{D_{KV}}$, Page I.29
Calculation of $C_{D_{KB}}$, Page I.30
Calculation of $C_{N_{BV}}$, Page I.31
Calculation of $C_{N_{B}}$, Page I.32
Calculation of $C_{N_{SR}}$, Page I.34
Engine-out Calculation, Page I.35
Wing Lift Curve Slope \( (M = 0.7) \)

\[
S = 4.49 \\
\frac{\Delta C_{L}}{\Delta \alpha} = 15^\circ = 0.2618 \text{ rad} \\
A = 12
\]

From Ref 5, Figure 3.12.

For \( A = 12 \)

\[
K = 1 + \frac{[(8.2 - 2.3 \frac{\Delta C_{L}}{\Delta \alpha}) - (22 - 15.3 \frac{\Delta C_{L}}{\Delta \alpha})A]}{100} \\
K = 1.0544
\]

\[
\frac{\Delta C_{L}}{\Delta \alpha} = 11.12^\circ \\
\tan \frac{\Delta C_{L}}{\Delta \alpha} = 0.1965
\]

\[
C_{L_{max}} = 6.0 \text{ rad}^{-1} \quad (C_{L_{max}} = 0.006) \\
B = \sqrt{1 - M^2} = \sqrt{1 - (0.7)^2} = 0.7141
\]

\[
K = \frac{C_{L_{max}}}{2\pi} = 0.6820
\]

\[
C_{L_{max}} = \frac{2\pi A}{\left(2 + \left(\frac{\pi B^2}{\Delta C_{L}}\right)\left(1 + \frac{\Delta C_{L}}{\Delta \alpha} \right) + 4\right)K}
\]

\[
C_{L_{max}} = 4.71 \text{ rad}^{-1} \quad \text{at} \ M = 0.7
\]

\[
4.89 \text{ rad}^{-1} \quad \text{at} \ M = 0.15
\]
**Calculation of** $C_{L,4}$

\[ \beta = 0.2669 \]

\[ C_{L,0} = 6.0 \text{ rad}^{-1} \]

\[ \beta^2 = 0.51 \]

\[ K = 1.0673 \]

\[ C_{L,4} = \frac{2 \pi \beta^4}{\left( 2 + \frac{16 \beta^2}{(26.69)^2} \left( 1 + \frac{(26.69)^2}{0.51} \right) + 4 \right)} \times 1.0673 \]

\[ C_{L,4} = 3.41 \text{ rad}^{-1} \text{ at } M = 0.7 \]

Using Ref. 5, Fig 3.12

\[ 3.46 \text{ rad}^{-1} \text{ at } M = 0.15 \]
Calculation of $\frac{dx}{d\lambda}$ (using Reference 5.)

From Figure 3.25

$m = 320'' / 410'' = 0.78$
$r = 425'' / 410'' = 1.073$

$\lambda = 0.4$

For $\lambda = 0.33$, $A = 12$

$\frac{dx}{d\lambda} = 0.244$

$\lambda = 0.20$

$\frac{dx}{d\lambda} = 0.250$

For $\lambda = 0.4$

$\frac{dx}{d\lambda} = \frac{0.250}{0.244} = \frac{1.250}{0.13} = \frac{2.44 - 2.50}{1.073}$

$\frac{dx}{d\lambda} = 2.41$

From Figure 3.46

$A = 12$, suspect $\frac{dx}{d\lambda}$ of a factor .78

$\boxed{\frac{dx}{d\lambda} = 0.236}$

$(1 - \frac{dx}{d\lambda}) = 0.764$
**MULTZOP's INTEGRATION** for $\Delta XACB$ (36 PAk)

$$\frac{dN}{dx} = \frac{9}{36.5} \sum_{i=1}^{n} W_i(x_i) \frac{df}{dx} \Delta x_i \text{ deg}^{-1}$$

<table>
<thead>
<tr>
<th>$W_i(x_i)$</th>
<th>$\Delta x_i$</th>
<th>$W_i^2(x_i)$</th>
<th>$x_i$</th>
<th>$\frac{df}{dx}$</th>
<th>$\frac{d\theta}{dx}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.03</td>
<td>70</td>
<td>3969</td>
<td>401</td>
<td>1.03</td>
<td>1.06</td>
</tr>
<tr>
<td>0.08</td>
<td>100</td>
<td>7749</td>
<td>231</td>
<td>1.05</td>
<td>1.08</td>
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<tr>
<td>0.06</td>
<td>100</td>
<td>9216</td>
<td>231</td>
<td>1.07</td>
<td>1.10</td>
</tr>
<tr>
<td>0.04</td>
<td>100</td>
<td>9216</td>
<td>131</td>
<td>1.12</td>
<td>1.15</td>
</tr>
<tr>
<td>0.06</td>
<td>62</td>
<td>9216</td>
<td>31</td>
<td>2.10</td>
<td>2.16</td>
</tr>
<tr>
<td>0.06</td>
<td>130</td>
<td>9216</td>
<td>65</td>
<td>.11</td>
<td></td>
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<tr>
<td>0.06</td>
<td>100</td>
<td>7376</td>
<td>165</td>
<td>.29</td>
<td></td>
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<tr>
<td>0.06</td>
<td>100</td>
<td>3844</td>
<td>165</td>
<td>.45</td>
<td></td>
</tr>
<tr>
<td>0.02</td>
<td>70</td>
<td>484</td>
<td>335</td>
<td>.59</td>
<td></td>
</tr>
<tr>
<td>0.04</td>
<td>110</td>
<td>1600</td>
<td>65</td>
<td>.11</td>
<td></td>
</tr>
<tr>
<td>0.04</td>
<td>110</td>
<td>1600</td>
<td>65</td>
<td>.11</td>
<td></td>
</tr>
</tbody>
</table>

$C_x = 100^\circ$

$\Delta H = 436^\circ$

$E = 50^\circ$

$\varphi = 215.6^\circ$, $PSI = 1.397$ PSI

$C_{XW} = 10.22$ deg

$E = 78^\circ$

$\frac{df}{dx} = 2.36$

From REF 5, Section 3.4.6
\[ \frac{d \mathfrak{f}^2(k_i)}{dk} \Delta k_i \]

\begin{align*}
1 & \quad 294500 \\
2 & \quad 816352 \\
3 & \quad 1013760 \\
4 & \quad 1659840 \\
5 & \quad 1234207 \\
6 & \quad 137189 \\
7 & \quad 214484 \\
8 & \quad 172988 \\
9 & \quad 19989 \\
10 & \quad 19360 \\
\Sigma & \quad 5016621
\end{align*}

\[ \frac{dm}{d\alpha} = \frac{q}{26.5} (5016621) \]

\[ \Delta K_{ACB} = \frac{\frac{dm}{d\alpha}}{q \Delta z} = \frac{5016621}{26.5} \frac{1}{(144)(144)(78)(0822)} \]

\[ \Delta K_{ACD} = 0.33 \]

\[ K_{ACD} = \frac{K_{ACB} + \Delta K_{ACD}}{2} \]

\[ K_{ACD} = 125 - 0.33 \]

\[ K_{ACD} = 124.67 \]
Calculation for $\overline{K_{AC}}$

From Reference 2, Chapter 11.

\[
\overline{K_{AC}}_{WB} = -0.08
\]

\[
C_{\text{CLU}} = 3.41 \text{ rad}^{-1}
\]

\[
\frac{d\varphi}{d\alpha} = 0.236
\]

\[
\overline{K_{AC}}_n = 6.40
\]

\[
C_{\varphi WB} = 4.71 \text{ rad}^{-1}
\]

\[
\overline{K_{AC}} = \frac{-0.08 + 3.41 \left( 0.764 \right) \left( 1.537 \right) 2.40}{4.71} \quad \text{Ref. 2.}
\]

\[
1 + \frac{3.41 \left( 0.764 \right) \left( 1.537 \right)}{4.71}
\]

\[
\overline{K_{AC}} = -0.43
\]

FS = 605

Let $\varphi = 57.1$, FS

\[
\varphi = 78^\circ
\]

Writing $K_{AC}$ in terms of SH/S results

IN!
\[ \bar{X}_{\text{AC}} = \frac{-0.08 + 3.54 (\text{Sd}/5)}{1 + 0.553 (\text{Sd}/5)} \]

<table>
<thead>
<tr>
<th>( \bar{X}_{\text{AC}} )</th>
<th>Sd</th>
<th>( \text{Sd}/5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.07</td>
<td>20</td>
<td>0.44</td>
</tr>
<tr>
<td>0.22</td>
<td>40</td>
<td>0.09</td>
</tr>
<tr>
<td>0.36</td>
<td>60</td>
<td>0.13</td>
</tr>
<tr>
<td>0.50</td>
<td>80</td>
<td>0.18</td>
</tr>
<tr>
<td>0.63</td>
<td>100</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Plotted in Figure 1.2

\[ \bar{X}_{\text{C6}} \text{ Sheet due to increased till area} \]

\[ \frac{W_{\text{H}}}{S_{\text{H}}} = 5.76 \text{ lbs/ft}^2 \text{ from Class I W+D} \]

<table>
<thead>
<tr>
<th>Sd</th>
<th>W_{\text{H}}</th>
<th>|W_{\text{H}}|</th>
<th>X_{\text{C6}}</th>
<th>\bar{X}_{\text{C6}}</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>115.2</td>
<td>565.2</td>
<td>592</td>
<td>.27</td>
</tr>
<tr>
<td>40</td>
<td>230.4</td>
<td>680.4</td>
<td>594</td>
<td>.29</td>
</tr>
<tr>
<td>60</td>
<td>345.6</td>
<td>795.6</td>
<td>596</td>
<td>.32</td>
</tr>
<tr>
<td>80</td>
<td>460.8</td>
<td>910.8</td>
<td>598</td>
<td>.35</td>
</tr>
<tr>
<td>100</td>
<td>576.0</td>
<td>1026.0</td>
<td>600</td>
<td>.37</td>
</tr>
</tbody>
</table>

Plotted in Figure 1.3
**Calculation of \( C_{\alpha V} \)**

\[ S = 78 \text{ ft}^2 \]
\[ \alpha_c = 45^\circ \]
\[ \lambda = .5 \]
\[ x_v = 33.42 \text{ ft} \]
\[ b_v = 73.4 \text{ ft} \]
\[ A = 1.2 \]
\[ K = 1.0242 \]
\[ \tan \frac{\alpha_c}{2} = .7436 \]
\[ B^2 = .51 \]
\[ x = .682 \]

\[ C_{\alpha V} = \frac{2 \pi (1.3)}{(2 + \sqrt{\frac{(1.3)^2 (0.17)}{46842} (1 + \frac{.7436}{.51}) + 4})} \times 1.0243 \]

\[ C_{\alpha V} = 1.66 \text{ rad} \quad M = .7 \]

From: Reference 5, Figure 3.12
Calculation of $C_{nB_B}$

$$C_{nB_B} = -57.3 \frac{K_N K_B}{b} \frac{S_{Bb}}{s} \frac{L_B}{b} \approx 2.0 \times 10^{-1}$$

$L_B = 78.1 \text{ ft}$

$L = 44.9 \text{ ft}$

$b = 73.4 \text{ ft}$

$S_{Bb} = 50.1 \text{ ft}^2$

$L_m = 41.42 \text{ ft}$

$h_l = 61''$

$h = 65''$

$h = 96''$

$\theta = 96^\circ$

$K_N = 0.001$

$$R_L = \frac{V_{L_B}}{V_w} \approx 0.003 \text{ ft/sec} \quad V = 696.3 \text{ ft/sec}$$

$$R_L = 1.56 \times 10^8$$

$K_{R2} = 2.03$

$$C_{nB_B} = -57.3 \times 1.001 \times (2.03) \left( \frac{50.1}{44.9} \right) \left( \frac{78.1}{73.4} \right)$$

$$C_{nB_B} = -0.138$$

*Note: Method in Reference 6.*
Calculation of $C_{r_BV}\\n
C_{r_BV} = C_{L_{v}} \frac{S_B}{S_L} \frac{K_V}{b}\\n
C_{r_BV} = 1.66 \left( \frac{S_B}{S_L} \right) \left( \frac{33.4^2}{73.4^2} \right)\\n
C_{r_BV} = .0017 S_B$
Calculation of \( C_{bo} \)

\[ C_{bo} = C_{bo}^{o} + C_{bo}^{w}, \]

Reference 2, Eqn. 11.

\[ C_{bo} = -1.138 + 0.00175v \]

\[
\begin{array}{c|c}
S_v \text{ (ft)} & C_{bo} \text{ (deg-1)} \\
20 & -0.0018 \\
40 & -0.0012 \\
60 & -0.0006 \\
80 & 0 \\
100 & 0.0006 \\
120 & 0.0012 \\
\end{array}
\]

\[ S_{v, leq} = 115 \text{ ft}^2 \] to achieve \( C_{bo} = 0.001 \text{ deg}^{-1} \)

\[ S_v = 130 \text{ ft}^2 \] at \( C_{bo} = 1.5/6 \text{ rad/deg} \)

Achieves a \( C_{bo} = 0.001 \text{ deg}^{-1} \)

See Figure 1.3
Figure 2-3
Lateral Directional X-Plot
for the 36 Passenger Commuter

UNIVERSITY OF KANSAS
Estimating \( C_{\nu S_R} \) for Sight-out Calculation

\[
C_{\nu S_R} = C_{L_{x,v}} \left( \frac{\alpha_6}{\alpha_5} \right) \left( \frac{\alpha_6}{\alpha_5} \right) K' K_b \frac{S_v}{S} \]

\[
C_{L_{x,v}} = 1.98 \times 10^{-1} \quad \text{AT } M = 0
\]

\[
\frac{\alpha_6}{\alpha_5} = -0.71
\]

\[
\frac{\alpha_6}{\alpha_5} = 1.11
\]

\[
K_b = 1
\]

\[
K' = 0.65
\]

\[
C_{\nu S_R} = -1.014 \frac{S_v}{S}
\]

\[
C_{\gamma S_R} = -C_{\nu S_R} \frac{K_b}{b}
\]

\[
C_{\gamma S_R} = 0.462 \frac{S_v}{\alpha_5}
\]

\[
C_{\nu S_R} = 0.001 \frac{S_v}{S}
\]

From Memo in Reference 6.
Engine - Out Calculation

From Method in Reference 2, Section 11.3

$Y_{TEFF} = 6.25\ ft$

$P_{TO req} = 4485\ \text{in}^2\ \text{Engire}$

$T_{TO} = \frac{550\ P_{TO} \ A_p}{V_{TO}}$

$A_p = 0.80$

$V_{TO} = 225\ \text{ft/sec} = 1.1\ V_{5TO}$

$\therefore\ T_{TO} = 8751\ \text{lbs}$

$N_{crit} = T_{TO} \cdot Y_{TEFF} = 54694\ \text{ft-lbs}$

$N_4 = 1.25\ N_{crit}$

$V_{MC} = 1.2\ V_{5L}$

$V_{5L} = 140\ \text{ft/sec}$

$V_{MC} = 168\ \text{ft/sec}$

$q_{MC} = 33.54\ \text{PSF, at 5500\ ft}$

$S_p = (N_{crit} + N_4) / (2\ mc \ S_0 \ Cos \ psi)$ (ii)

$S_2 = \frac{56.27}{S_v}$

For $S_v = 130\ \text{ft}$

$\beta_2 = 24.8^\circ$ to hold Engine Out.
RESIZED VERTICAL TAIL TO HOLD ENGINE OUT

\[ S_V = 130 \text{ ft}^2 \]
\[ b_V = 12 \text{ ft} \]
\[ A_V = 1.11 \]
\[ C_L = 5 \text{ ft} \]
\[ C_r = 16.67 \text{ ft} \]
\[ \lambda_V = 0.3 \]
\[ \frac{C_r}{C_V} = 0.35 \]
\[ Z_V = 11.9 \text{ ft} \]
I.8 Calculation of Class I Drag Polar

This section computed the airplane wetted area and estimated skin friction drag. Class I drag polars are constructed and compared with the polars computed for the performance given. Table I.9 contains a wetted area breakdown.
List of Components that Contribute to Wetted Area:

- Fuselage
- Wing
- Empennage
- Nacelles
- Pylons

1) Wing

\[ S_{\text{wet}} = 2S_{\text{exp}} \left[ 1 + 0.25 \left( \frac{c}{c_r} \right) \left( 1 + \lambda \right) / (1 + \lambda) \right] \]

\[ S_{\text{exp}} = \frac{B_{\text{exp}}}{W_{\text{exp}}} (1 + \lambda) \]

\[ S_{\text{exp}} = \frac{65.4}{2} (1.223) (1 + \lambda) \]

\[ S_{\text{exp}} = 381.5 \text{ ft}^2 \]

\[ 2S_{\text{exp}} = 763 \text{ ft}^2 \]

\[ \left( \frac{c}{c_r} \right) = 0.13 \]

\[ \lambda = 1 \]

\[ S_{\text{wet}} = 763 \times \left( 1.0225 \right) \]

\[ S_{\text{wet}} = 781.8 \text{ ft}^2 \]
**Horizontal Tail**

\[ S_{exp} = 69 \]

\[ \lambda = .7 \]

\[ \tau = 1 \]

\[ (c/c)_{r} = .11 \]

\[ S_{wet} = 2(69)[1 + .25(0.11)(1+0.7)/(1.7)] \]

\[ S_{wet} = 142 \text{ ft}^2 \]

**Vertical Tail**

\[ S_{exp} = 130 \text{ ft}^2 \]

\[ \lambda = .3 \]

\[ \tau = 1 \]

\[ (c/c)_{r} = .11 \]

\[ S_{wet} = 2(130)[1 + .25(0.11)(1+0.3)/(0.3)] \]

\[ S_{wet} = 267 \text{ ft}^2 \]
Fuselage

$$Sw_{\text{Fus}} = \pi D_f l_f \left(1 - \frac{2}{D_f} \right)^{2/3} \left(1 + \frac{1}{D_f} \right)^{1/3}$$

$$D_f = \frac{l_f}{D_f} = 9.76$$

$$l_f = 78.1 \text{ ft}$$

$$Sw_{\text{Fus}} = \pi \left(9.76\right) \left(78.1\right) \left(1 - \frac{2}{9.76}\right)^{2/3} \left(1 + \frac{1}{9.76}\right)^{1/3}$$

$$= \pi \left(9.76\right) \left(78.1\right) \left(0.9582\right) \left(1.0105\right)$$

$$Sw_{\text{Fus}} = 1702 \text{ ft}^2$$

Nacelle

$$Sw_{\text{n}} = \pi \left( \frac{D_{\text{n}}}{2} \right)^2$$

$$Sw_{\text{n}} = \pi \left( \frac{108.5}{2} \right)^2$$

$$Sw_{\text{n}} = 90 \text{ ft}^2$$

Total Engine Nacelle Wetted Area = 180 ft²

Pylon

$$Sw_{\text{pylon}} = 2 \pi \left( \frac{D_{\text{pylon}}}{2} \right)^2 \left[ \frac{1 + 0.25 (\frac{D_{\text{pylon}}}{l_{\text{pylon}}})}{(1 + 0.25)} \right]$$

$$l = 1$$

$$\frac{k}{c_{\text{pylon}}} = 1.2$$

$$c = 1$$

$$Sw_{\text{pylon}} = 2 \pi \left( \frac{10.5}{2} \right)^2 \left[ \frac{1 + 0.25 (1.2)}{(1 + 0.25)} \right]$$

$$Sw_{\text{pylon}} = 62 \text{ ft}^2$$

$$2 \text{ pylons} = 124 \text{ ft}^2 = Sw_{\text{pylon}}$$
### Table I.9 Wetted Area of 36 Passenger Airplane Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Wetted Area (ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing</td>
<td>788</td>
</tr>
<tr>
<td>H-Tail</td>
<td>142</td>
</tr>
<tr>
<td>V-Tail</td>
<td>267</td>
</tr>
<tr>
<td>Fuselage</td>
<td>1702</td>
</tr>
<tr>
<td>Engine Nacelles</td>
<td>90 x 2</td>
</tr>
<tr>
<td>Engine Pylons</td>
<td>62 x 2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3203</strong></td>
</tr>
</tbody>
</table>

From Figure 3.21 Roskam's Part I

\[ f = 7.8 \text{ ft}² \]

\[ C_{D0} = f/s = 0.0174 \]

Add 0.0002 to \( C_{D0} \) for compressibility effects.

\[ C_{D0} = 0.0176 \]

Take-off \( C_{D0} \) increment:

- 0.015 for gear

Launch \( C_{D0} \) increment:

- 0.015 for gear
- 0.075 for flaps
**Drag Polars**

**Take-Off**

\[ C_{D_0} = 0.174 + 0.015 \]
\[ = 0.334 \]

\[ \epsilon = 0.80 \]
\[ A = 12 \]

\[ C_{D} = C_{D_0} + \frac{C_{L}^2}{\pi A \epsilon} \]

\[ C_{D} = 0.324 + 0.032 C_{L}^2 \]

**Cruise**

\[ C_{D_0} = 0.0176 \]

\[ \epsilon = 0.85 \]
\[ A = 12 \]

\[ C_{D} = 0.0176 + 0.0312 C_{L}^2 \]

**Landing**

\[ C_{D_0} = 0.0174 + 0.09 \]
\[ = 0.1674 \]

\[ \epsilon = 0.8 \]
\[ A = 12 \]

\[ C_{D} = 0.1074 + 0.0332 C_{L}^2 \]
\[ C_{L_{cruise}} = 0.3 \]
\[ (L/D)_{cr} = 14.92 \]

By taking a 10% reduction in \( C_{D_0} \)
\[ 0.0173 \times 0.9 = 0.0156 \]
\[ C_{D} = 0.0156 + 0.0312 \, C_{L^2} \]
\[ (L/D)_{cr} = 16.32 \]

Utilizing NLF should allow a 10% reduction in actual \( C_{D_0} \).

From initial weight since an
\[ (L/D)_{cr} = 16 \text{ was assumed} \]
and:
\[ \frac{\Delta WT}{\Delta L/D} = -774.4 \text{ was calculated.} \]

\[ \Delta L/D = \text{Class I L/D} - \text{Init. L/D} \]
\[ = 14.92 - 16 \]
\[ = -1.08 \]

Therefore:
\[ \Delta WT = \frac{\Delta WT}{\Delta L/D} \, \Delta L/D. \]
\[ \Delta WT = 836 \text{ lbs increase.} \]
\[ W_{TO \, new} = W_{TO} + \Delta W_{TO} \]

\[ W_{TO \, new} = 3,395 + 836 \]

\[ = 4,231 \, \text{lbs} \]

This represents an 2.7% change in take-off weight. This magnitude of change does not warrant resizing.
APPENDIX J

ENGINEERING CALCULATIONS FOR
THE 50 PASSENGER COMMUTER
TABLE OF CONTENTS

J.1  INTRODUCTION                    PAGE  J.3
J.2  PRELIMINARY WEIGHT SIZING       J.4
J.3  PRELIMINARY PERFORMANCE SIZING  J.6
J.4  CLASS I FLAP SIZING              J.12
J.5  CLASS I EMPENNAGE SIZING         J.16
J.6  LANDING GEAR CRITERION          J.18
J.7  STABILITY AND CONTROL CALCULATIONS  J.20
J.8  CLASS I DRAG POLARS             J.36
J.1 INTRODUCTION

The purpose of this appendix is to present the preliminary sizing and Class I design calculations. Methods used were taken from References 1 and 2. References 5 and 6 are used for stability and control design considerations.

Section J.2 contains preliminary weight sizing calculations. These results are from XEWTOG, a computer program available at the University of Kansas.

Section J.3 contains preliminary performance results from XPRFRM, another computer program at K.U.

Section J.4 contains Class I flap sizing calculations.

Section J.5 contains Class I empennage sizing (V-bar method).

Section J.6 contains landing gear design criteria.

Section J.7 contains stability and control calculations.

Section J.8 contains the wetted area calculations and the Class I drag polars.
J.2 INITIAL WEIGHT SIZING

Using XEWTOG, a weight sizing program which follows the method in Chapter 2 of Reference 1, the following weights and take-off weight sensitivities are determined for the 50 passenger airplane. See Table J.1.

The design assumptions used in the weight sizing are:

$$(L/D)_{cr} = 16$$

$c_p = 0.4 \text{ lbs/\text{hp/hour}}$

$n_p = 0.85$

$V_{cr} = 442 \text{ kts}$
### Table J.1 Initial Weight Sizing Results with Sensitivities

**Weight Estimation for a Regional Propeller Driven Aircraft**
- **Passenger Weight:** 10250 lbs
- **Cargo Weight:** 0 lbs
- **Crew Weight:** 515 lbs

**Phase w/ CJ or CP NP L/D ALTCR RC MCR OR V E OR R PLOP**

<table>
<thead>
<tr>
<th></th>
<th>0.999</th>
<th>0.00</th>
<th>0.00</th>
<th>0.00</th>
<th>0.00</th>
<th>0.00</th>
<th>0.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.995</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>0.995</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>0.995</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>0.994</td>
<td>0.50</td>
<td>0.77</td>
<td>15.00</td>
<td>3000.0</td>
<td>3000.0</td>
<td>270.00</td>
</tr>
<tr>
<td>5</td>
<td>0.909</td>
<td>0.40</td>
<td>0.85</td>
<td>16.00</td>
<td>0.00</td>
<td>0.00</td>
<td>1055.00</td>
</tr>
<tr>
<td>6</td>
<td>0.985</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>7</td>
<td>0.995</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>8</td>
<td>0.995</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Regression coefficients are \( a = 0.3989 \) and \( b = 0.9647 \)

- **Mission Fuel Fraction without Reserves:** 0.868
- **Gross Take-Off Weight:** 42057 lbs
- **Empty Weight:** 23963 lbs
- **Weight of Fuel:** 6813 lbs

"??? Empty Weight Reduction due to Composites: 5.0 per cent"

**Sensitivity Analysis Begins Here**

- **Growth Factor due to Payload Weight:** 4.2
- **Take-Off Weight to Empty Weight Sensitivity:** 1.7

<table>
<thead>
<tr>
<th>Choice Number</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climb to Cruise</td>
<td>****</td>
<td>****</td>
</tr>
<tr>
<td>Cruise</td>
<td>****</td>
<td>****</td>
</tr>
<tr>
<td>SFC (LB/LB/HR)</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>SFC (LB/HP/HR)</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Prop Efficiency</td>
<td>0.77</td>
<td>0.85</td>
</tr>
<tr>
<td>L/D</td>
<td>16.0</td>
<td>16.0</td>
</tr>
<tr>
<td>Velocity (KNOTS)</td>
<td>270.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Range (MT. MILES)</td>
<td>1055.0</td>
<td>1055.0</td>
</tr>
<tr>
<td>Endurance (HRS)</td>
<td>5619.8</td>
<td>0.0</td>
</tr>
</tbody>
</table>

The sensitivity of Gross Take-Off Weight to the following parameters is now given as the partial derivative of the Gross Take-Off Weight to the indicated parameter.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Partial Derivative</th>
</tr>
</thead>
<tbody>
<tr>
<td>DWTO/DCJ (LB/LB/LB/HR)</td>
<td>0.0</td>
</tr>
<tr>
<td>DWTO/DCP (LB/LB/HP/HR)</td>
<td>0.0</td>
</tr>
<tr>
<td>DWTO/DNP (POUNDS)</td>
<td>0.0</td>
</tr>
<tr>
<td>DWTO/D(L/D) (POUNDS)</td>
<td>0.0</td>
</tr>
<tr>
<td>DWTO/DV (LB/KNOT)</td>
<td>0.0</td>
</tr>
<tr>
<td>DWTO/DR (LB/NT MILE)</td>
<td>0.0</td>
</tr>
<tr>
<td>DWTO/DE (LB/HR)</td>
<td>5619.8</td>
</tr>
</tbody>
</table>
J.3 INITIAL PERFORMANCE SIZING

The results from XPRFRM, a performance sizing program, are given in this section. The methods used are in Ch. 3 of Reference 2. See Tables J.3 through J.6.
### TABLE J.2 TAKE-OFF SIZING

<table>
<thead>
<tr>
<th>Input Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude</td>
<td></td>
</tr>
<tr>
<td>Minimum take-off distance (STC)</td>
<td>0.8 (FT)</td>
</tr>
<tr>
<td>Maximum wing loading</td>
<td>2.0 (SLUG/FT²)</td>
</tr>
<tr>
<td>Minimum take-off lift coefficient</td>
<td>1.20</td>
</tr>
<tr>
<td>Maximum take-off lift coefficient</td>
<td>2.20</td>
</tr>
</tbody>
</table>

**OUTPUT DATA**

**TABLE OF POWER LOADINGS**

<table>
<thead>
<tr>
<th>W/S</th>
<th>CLMAX TO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>1.06  1.25  1.50  2.05  2.76</td>
</tr>
<tr>
<td>2.00</td>
<td>1.34  1.62  1.90  2.47  3.15</td>
</tr>
<tr>
<td>3.00</td>
<td>1.54  1.82  2.10  2.67  3.40</td>
</tr>
<tr>
<td>4.00</td>
<td>1.73  2.01  2.30  2.87  3.60</td>
</tr>
<tr>
<td>5.00</td>
<td>1.92  2.20  2.49  3.07  3.80</td>
</tr>
</tbody>
</table>

---

### TABLE J.3 LANDING FIELD LENGTH SIZING

**REGIONAL TURBO-PROP**

**FAA 25 CERTIFICATION CATEGORY**

<table>
<thead>
<tr>
<th>Gross take-off weight (WT)</th>
<th>42057 (LBS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landing to take-off weight ratio</td>
<td>1.064</td>
</tr>
<tr>
<td>Elevation</td>
<td>1000 (FEET)</td>
</tr>
<tr>
<td>Density</td>
<td>.0237 (SLUG/FT²)</td>
</tr>
<tr>
<td>Landing approach speed (VA)</td>
<td>110 (KTS)</td>
</tr>
<tr>
<td>Landing field length (SFL)</td>
<td>15000 (FEET)</td>
</tr>
</tbody>
</table>

(-/5) TO = 23.00 CLMAX (LAND)

**MAXIMUM TAKE-OFF WING LOADINGS**

To meet landing distance requirement

<table>
<thead>
<tr>
<th>CLMAX (LAND)</th>
<th>Maximum wing loading (TAKE-OFF) (CL/FT²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>51.40</td>
</tr>
<tr>
<td>1.50</td>
<td>60.17</td>
</tr>
<tr>
<td>2.00</td>
<td>70.17</td>
</tr>
<tr>
<td>2.50</td>
<td>70.17</td>
</tr>
</tbody>
</table>

*ORIGINAL PAGE IS OF POOR QUALITY*
## Table J.4 Initial Drag Polars

### Drag Polar Equations

#### Input Data

- Maximum Take-Off Weight (Clean) \( 45000 \text{ lb} \) (Eqn. 1)
- Aspect Ratio \( 12.9 \) (Eqn. 2)
- Skin Friction Coefficient \( 0.0025 \)
- Airplane Wettability \( 0.70 \) (Eqn. 2)
- Drag Increment Due to Take-Off Flaps \( 0.6 \)
- Drag Increment Due to Landing Flaps \( 1.20 \)
- Oswald Efficiency Factor (Clean) \( 0.95 \)
- Oswald Efficiency Factor (Take-Off) \( 0.85 \)
- Oswald Efficiency Factor (Landing) \( 0.80 \)

#### Calculated Data

The complete set of drag polars is:

1. **Clean**: \( C_D = 0.0025 + 0.10 \) \( \text{CL}_{\text{max}} = 10.7 \) \( L/D_{\text{max}} = 10.7 \)
2. **Take-Off (Landing Gear Up)**: \( C_D = 0.0025 + 0.15 \) \( \text{CL}_{\text{max}} = 13.1 \) \( L/D_{\text{max}} = 13.1 \)
3. **Take-Off (Landing Gear Down)**: \( C_D = 0.0025 + 0.15 \) \( \text{CL}_{\text{max}} = 10.9 \) \( L/D_{\text{max}} = 10.9 \)
4. **Landing (Landing Gear Up)**: \( C_D = 0.0025 + 0.10 \) \( \text{CL}_{\text{max}} = 11.3 \) \( L/D_{\text{max}} = 11.3 \)
5. **Landing (Landing Gear Down)**: \( C_D = 0.0025 + 0.10 \) \( \text{CL}_{\text{max}} = 9.8 \) \( L/D_{\text{max}} = 9.8 \)

---

Original page is of poor quality.
### Table J.5a)

**PAR 25.111 (CFI) "INITIAL CLIMB SEGMENT"**

**PAR 25.111 CLIMB GRADIENT (INITIAL SEGMENT) 1.2000**

**TABLE OF POWER LOADINGS REQUIRED**

<table>
<thead>
<tr>
<th>Aspect ratio</th>
<th>0.00</th>
<th>40.00</th>
<th>60.00</th>
<th>80.00</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.40</td>
<td>71.5</td>
<td>65.8</td>
<td>61.4</td>
<td>49.7</td>
<td>47.8</td>
</tr>
<tr>
<td>0.50</td>
<td>76.6</td>
<td>70.6</td>
<td>66.1</td>
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<td>53.0</td>
</tr>
<tr>
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<td>63.8</td>
<td>58.4</td>
<td>53.1</td>
<td>45.8</td>
<td>44.0</td>
</tr>
<tr>
<td>0.70</td>
<td>52.5</td>
<td>47.4</td>
<td>42.4</td>
<td>36.7</td>
<td>35.0</td>
</tr>
<tr>
<td>0.80</td>
<td>43.5</td>
<td>38.9</td>
<td>34.2</td>
<td>29.2</td>
<td>27.6</td>
</tr>
<tr>
<td>0.90</td>
<td>36.0</td>
<td>32.0</td>
<td>28.1</td>
<td>23.7</td>
<td>22.2</td>
</tr>
</tbody>
</table>

### Table J.5b)

**PAR 25.121 (CFI) "SECOND SEGMENT CLIMB"**

**PAR 25.121 CLIMB GRADIENT (SECOND SEGMENT) 2.4000**

**TABLE OF POWER LOADINGS REQUIRED**

<table>
<thead>
<tr>
<th>Aspect ratio</th>
<th>0.00</th>
<th>40.00</th>
<th>60.00</th>
<th>80.00</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.40</td>
<td>71.5</td>
<td>65.8</td>
<td>61.4</td>
<td>49.7</td>
<td>47.8</td>
</tr>
<tr>
<td>0.50</td>
<td>76.6</td>
<td>70.6</td>
<td>66.1</td>
<td>54.9</td>
<td>53.0</td>
</tr>
<tr>
<td>0.60</td>
<td>63.8</td>
<td>58.4</td>
<td>53.1</td>
<td>45.8</td>
<td>44.0</td>
</tr>
<tr>
<td>0.70</td>
<td>52.5</td>
<td>47.4</td>
<td>42.4</td>
<td>36.7</td>
<td>35.0</td>
</tr>
<tr>
<td>0.80</td>
<td>43.5</td>
<td>38.9</td>
<td>34.2</td>
<td>29.2</td>
<td>27.6</td>
</tr>
<tr>
<td>0.90</td>
<td>36.0</td>
<td>32.0</td>
<td>28.1</td>
<td>23.7</td>
<td>22.2</td>
</tr>
</tbody>
</table>

### Table J.5c)

**PAR 25.121 (CFI) "TRANSITION SEGMENT CLIMB"**

**PAR 25.121 CLIMB GRADIENT (TRANSITION) 0.3010**

**TABLE OF POWER LOADINGS REQUIRED**

<table>
<thead>
<tr>
<th>Aspect ratio</th>
<th>0.00</th>
<th>40.00</th>
<th>60.00</th>
<th>80.00</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.40</td>
<td>71.5</td>
<td>65.8</td>
<td>61.4</td>
<td>49.7</td>
<td>47.8</td>
</tr>
<tr>
<td>0.50</td>
<td>76.6</td>
<td>70.6</td>
<td>66.1</td>
<td>54.9</td>
<td>53.0</td>
</tr>
<tr>
<td>0.60</td>
<td>63.8</td>
<td>58.4</td>
<td>53.1</td>
<td>45.8</td>
<td>44.0</td>
</tr>
<tr>
<td>0.70</td>
<td>52.5</td>
<td>47.4</td>
<td>42.4</td>
<td>36.7</td>
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</tr>
<tr>
<td>0.80</td>
<td>43.5</td>
<td>38.9</td>
<td>34.2</td>
<td>29.2</td>
<td>27.6</td>
</tr>
<tr>
<td>0.90</td>
<td>36.0</td>
<td>32.0</td>
<td>28.1</td>
<td>23.7</td>
<td>22.2</td>
</tr>
</tbody>
</table>

J.9
### TABLE J.5 a)

**Example:**

**Table of Power Loadings Required**

<table>
<thead>
<tr>
<th>Aspect Ratio</th>
<th>10:00</th>
<th>11:00</th>
<th>12:00</th>
<th>13:00</th>
<th>14:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.14</td>
<td>5.92</td>
<td>7.74</td>
<td>10.41</td>
<td>14.29</td>
</tr>
<tr>
<td>1.0</td>
<td>5.45</td>
<td>6.32</td>
<td>8.15</td>
<td>10.82</td>
<td>14.61</td>
</tr>
<tr>
<td>1.1</td>
<td>5.75</td>
<td>6.62</td>
<td>8.45</td>
<td>11.15</td>
<td>14.91</td>
</tr>
<tr>
<td>1.2</td>
<td>6.05</td>
<td>6.92</td>
<td>8.75</td>
<td>11.45</td>
<td>15.21</td>
</tr>
<tr>
<td>1.3</td>
<td>6.35</td>
<td>7.22</td>
<td>9.05</td>
<td>11.75</td>
<td>15.51</td>
</tr>
</tbody>
</table>

### TABLE J.5 b)

**Example:**

**Table of Power Loadings Required**

<table>
<thead>
<tr>
<th>Aspect Ratio</th>
<th>10:00</th>
<th>11:00</th>
<th>12:00</th>
<th>13:00</th>
<th>14:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.14</td>
<td>5.92</td>
<td>7.74</td>
<td>10.41</td>
<td>14.29</td>
</tr>
<tr>
<td>1.0</td>
<td>5.45</td>
<td>6.32</td>
<td>8.15</td>
<td>10.82</td>
<td>14.61</td>
</tr>
<tr>
<td>1.1</td>
<td>5.75</td>
<td>6.62</td>
<td>8.45</td>
<td>11.15</td>
<td>14.91</td>
</tr>
<tr>
<td>1.2</td>
<td>6.05</td>
<td>6.92</td>
<td>8.75</td>
<td>11.45</td>
<td>15.21</td>
</tr>
<tr>
<td>1.3</td>
<td>6.35</td>
<td>7.22</td>
<td>9.05</td>
<td>11.75</td>
<td>15.51</td>
</tr>
</tbody>
</table>

### TABLE J.5 c)

**Example:**

**Table of Power Loadings Required**

<table>
<thead>
<tr>
<th>Aspect Ratio</th>
<th>10:00</th>
<th>11:00</th>
<th>12:00</th>
<th>13:00</th>
<th>14:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.14</td>
<td>5.92</td>
<td>7.74</td>
<td>10.41</td>
<td>14.29</td>
</tr>
<tr>
<td>1.0</td>
<td>5.45</td>
<td>6.32</td>
<td>8.15</td>
<td>10.82</td>
<td>14.61</td>
</tr>
<tr>
<td>1.1</td>
<td>5.75</td>
<td>6.62</td>
<td>8.45</td>
<td>11.15</td>
<td>14.91</td>
</tr>
<tr>
<td>1.2</td>
<td>6.05</td>
<td>6.92</td>
<td>8.75</td>
<td>11.45</td>
<td>15.21</td>
</tr>
<tr>
<td>1.3</td>
<td>6.35</td>
<td>7.22</td>
<td>9.05</td>
<td>11.75</td>
<td>15.51</td>
</tr>
</tbody>
</table>

### TABLE J.5 d)

**Example:**

**Table of Power Loadings Required**

<table>
<thead>
<tr>
<th>Aspect Ratio</th>
<th>10:00</th>
<th>11:00</th>
<th>12:00</th>
<th>13:00</th>
<th>14:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.14</td>
<td>5.92</td>
<td>7.74</td>
<td>10.41</td>
<td>14.29</td>
</tr>
<tr>
<td>1.0</td>
<td>5.45</td>
<td>6.32</td>
<td>8.15</td>
<td>10.82</td>
<td>14.61</td>
</tr>
<tr>
<td>1.1</td>
<td>5.75</td>
<td>6.62</td>
<td>8.45</td>
<td>11.15</td>
<td>14.91</td>
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<tr>
<td>1.2</td>
<td>6.05</td>
<td>6.92</td>
<td>8.75</td>
<td>11.45</td>
<td>15.21</td>
</tr>
<tr>
<td>1.3</td>
<td>6.35</td>
<td>7.22</td>
<td>9.05</td>
<td>11.75</td>
<td>15.51</td>
</tr>
</tbody>
</table>

### TABLE J.5 e)

**Example:**

**Table of Power Loadings Required**

<table>
<thead>
<tr>
<th>Aspect Ratio</th>
<th>10:00</th>
<th>11:00</th>
<th>12:00</th>
<th>13:00</th>
<th>14:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.14</td>
<td>5.92</td>
<td>7.74</td>
<td>10.41</td>
<td>14.29</td>
</tr>
<tr>
<td>1.0</td>
<td>5.45</td>
<td>6.32</td>
<td>8.15</td>
<td>10.82</td>
<td>14.61</td>
</tr>
<tr>
<td>1.1</td>
<td>5.75</td>
<td>6.62</td>
<td>8.45</td>
<td>11.15</td>
<td>14.91</td>
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<tr>
<td>1.2</td>
<td>6.05</td>
<td>6.92</td>
<td>8.75</td>
<td>11.45</td>
<td>15.21</td>
</tr>
<tr>
<td>1.3</td>
<td>6.35</td>
<td>7.22</td>
<td>9.05</td>
<td>11.75</td>
<td>15.51</td>
</tr>
</tbody>
</table>

### TABLE J.5 f)

**Example:**

**Table of Power Loadings Required**

<table>
<thead>
<tr>
<th>Aspect Ratio</th>
<th>10:00</th>
<th>11:00</th>
<th>12:00</th>
<th>13:00</th>
<th>14:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.14</td>
<td>5.92</td>
<td>7.74</td>
<td>10.41</td>
<td>14.29</td>
</tr>
<tr>
<td>1.0</td>
<td>5.45</td>
<td>6.32</td>
<td>8.15</td>
<td>10.82</td>
<td>14.61</td>
</tr>
<tr>
<td>1.1</td>
<td>5.75</td>
<td>6.62</td>
<td>8.45</td>
<td>11.15</td>
<td>14.91</td>
</tr>
<tr>
<td>1.2</td>
<td>6.05</td>
<td>6.92</td>
<td>8.75</td>
<td>11.45</td>
<td>15.21</td>
</tr>
<tr>
<td>1.3</td>
<td>6.35</td>
<td>7.22</td>
<td>9.05</td>
<td>11.75</td>
<td>15.51</td>
</tr>
</tbody>
</table>
TABLE J.6

<table>
<thead>
<tr>
<th>(n/θ)</th>
<th>(v/θ)</th>
<th>(n/f)</th>
<th>(v/f)</th>
<th>(n/f)</th>
<th>(v/f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACTUAL</td>
<td>TAKEOFF</td>
<td>ACTUAL</td>
<td>TAKEOFF</td>
<td>FLIGHT</td>
<td>STATIC</td>
</tr>
<tr>
<td>EST</td>
<td>EST</td>
<td>(18/θ)</td>
<td>(18/θ)</td>
<td>(18/θ)</td>
<td>(18/θ)</td>
</tr>
<tr>
<td>17.5</td>
<td>30.0</td>
<td>2.16</td>
<td>1.97</td>
<td>2.05</td>
<td>1.17</td>
</tr>
<tr>
<td>10.0</td>
<td>15.0</td>
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<td>1.74</td>
<td>1.82</td>
<td>1.14</td>
</tr>
<tr>
<td>10.0</td>
<td>5.0</td>
<td>1.05</td>
<td>0.96</td>
<td>1.12</td>
<td>0.14</td>
</tr>
</tbody>
</table>

ORIGINAL PAGE IS OF POOR QUALITY
J.4 Flap Sizing

Using the method of Ref. 2, Ch. 7, it is determined that the following flap geometry will supply the incremental lift necessary for take-off and landing. See Table J.7. The design calculations follow.

Table J.7 50 Pax Flap Geometry

Type: Trailing Edge Fowler Flaps

\[ \frac{C_f}{C} = 0.25 \]
\[ \frac{S_{tf}}{S} = 0.682 \]
\[ \frac{b_f}{b} = 0.638 \]

Take-off  \( \delta_f = 20 \text{ deg} \)

Landing  \( \delta_f = 40 \text{ deg} \)

\[ \eta_i = 0.10 \]

\[ \eta_o = 0.738 \]
CLASS I FLAP SIZING - from Ch. 7, Ref. 2

\[ C_{L\text{max}} = 1.5 \]
\[ C_{L\text{max}_{\text{to}}} = 2.0 \]
\[ C_{L\text{max}_{\text{L}}} = 3.0 \]
\[ R_{N_T} = \frac{p V C_T}{\mu} = 1.28 \times 10^7 \]
\[ R_{N_L} = \frac{p V C_L}{\mu} = 5.11 \times 10^6 \]

From Fig. 7 of Ref. 2, a .13 airfoil yields

\[ C_{L\text{max}_{\text{root}}} = 1.85 \]
\[ C_{L\text{max}_{\text{tip}}} = 1.7 \]

With Eqn. (7.3)

\[ C_{L\text{max}_{\text{w}}} = 0.95(1.85 + 1.7)/2 = 1.69 \]

Using Eqn. (7.2)

\[ C_{L\text{max}_{\text{w}}} = \frac{C_{L\text{max}_{\text{unswept}}}}{\cos \Lambda c/H} \]

\[ C_{L\text{max}_{\text{w}}} = 1.65 \]

With Eqn (7.1) this yields

\[ C_{L\text{max}} = 1.65/1.08 = 1.53 \]

Therefore, the assumed value of \( C_{L\text{max}} = 1.5 \) is reasonable.
Incremental $C_{l\text{max}}$ values to be generated by the flaps:

Take-off: $\Delta C_{l\text{max}_{T0}} = 1.05 (C_{l\text{max}_{T0}} - C_{l\text{max}})$

$\Delta C_{l\text{max}} = 1.05 (C_{l\text{max}_{L}} - C_{l\text{max}})$

$\Delta C_{l\text{max}_{T0}} = 0.525$

$\Delta C_{l\text{max}_{L}} = 1.58$

From Eqn. (7.9) $K_A = 0.906$

Using Eqn. (7.8):

T.O.: $\Delta C_{l\text{max}} = 0.476 \text{ (S/SWF)}$

LAND: $\Delta C_{l\text{max}} = 1.43 \text{ (S/SWF)}$

Assuming Fowler flaps with

$C_{f}/C = 0.25 \quad \delta_{F,T0} = 20^\circ \quad \delta_{FL} = 40^\circ$

From Fig. 7.4, $K = 0.96$ and with Eqn. (7.11):

$\Delta C_l = (1/K) \Delta C_{l\text{max}}$

T.O.: $\Delta C_l = 0.496 \text{ (S/SWF)}$

LAND: $\Delta C_l = 1.49 \text{ (S/SWF)}$

Obtainable $\Delta C_l$ FLAP:

Using Eqn. (7.17), $C_{l_{\text{max}}} = 7.85$

Since $C_{l\text{max}_{L}}$ is more critical only it is considered.

From Fig. 7.8 $\alpha_{FL} = 0.40$

With Eqn. (7.14), $\Delta C_{l\text{max}_{L}} = 2.10$

Thus this will generate the required $C_{l\text{max}}$. 

J.14
J.5 V-BAR METHOD FOR EMPENNAGE SIZING

- Reference 2 Chapter 8

Conventional T-Tail type empennage

Taking an average value for $\overline{\nabla}_H$, $\overline{\nabla}_V$ from Tables 8.6a and 8.6b:

$$\overline{\nabla}_H = 1.08$$
$$\overline{\nabla}_V = 0.083$$

Similar averages are found for the following:

$$\frac{S_E}{S_H} = 0.36$$
$$\frac{S_{\alpha}}{S} = 0.06$$
$$\frac{S_{\tau}}{S_V} = 0.34$$

For the 50 pax:

$$S = 592 \, \text{ft}^2$$
$$\overline{c} = 7.46 \, \text{ft}$$
$$X_H = 36.7 \, \text{ft}$$
$$b = 84.3 \, \text{ft}$$
$$X_V = 31.9 \, \text{ft}$$

From Eqn. 8.3 Ref. 2

$$S_H = \overline{\nabla}_H S \overline{c} / X_H$$

$$\therefore \; S_H = 130 \, \text{ft}^2$$
From Eqn. (8.4),

\[ S_v = \frac{V_v S_b}{x_v} \]

\[ S_v = 130 \text{ ft}^2 \]

For the control surfaces

\[ S_a = 35.5 \text{ ft}^2 \]
\[ S_r = 44.2 \text{ ft}^2 \]
\[ S_e = 46.8 \text{ ft} \]

**Table J.8 Geometric Quantities for the Empennage**

<table>
<thead>
<tr>
<th>Horizontal Tail</th>
<th>Vertical Tail</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S_H = 130 \text{ ft}^2 )</td>
<td>( S_v = 130 \text{ ft}^2 )</td>
</tr>
<tr>
<td>( A_H = 5 )</td>
<td>( A_v = 1.4 )</td>
</tr>
<tr>
<td>( \lambda_H = 0.5 )</td>
<td>( \lambda_v = 0.5 )</td>
</tr>
<tr>
<td>( \Lambda_{LE} = 25^\circ )</td>
<td>( \Lambda_{LE} = 40^\circ )</td>
</tr>
<tr>
<td>( \bar{C}_H = 5.29 \text{ ft} )</td>
<td>( \bar{C}_v = 9.96 \text{ ft} )</td>
</tr>
<tr>
<td>( b_H = 25.5 \text{ ft} )</td>
<td>( b_v = 13.5 \text{ ft} )</td>
</tr>
<tr>
<td>( C_r = 6.80 \text{ ft} )</td>
<td>( C_r = 12.8 \text{ ft} )</td>
</tr>
<tr>
<td>( C_t = 3.40 \text{ ft} )</td>
<td>( C_t = 6.42 \text{ ft} )</td>
</tr>
<tr>
<td>( (t/c)_H = 0.12 \text{ root, } 0.10 \text{ tip} )</td>
<td>( (t/c)_v = 0.13 \text{ root, } 0.12 \text{ tip} )</td>
</tr>
<tr>
<td>( \Gamma = 0^\circ )</td>
<td>( \Gamma = 90^\circ )</td>
</tr>
<tr>
<td>( i = 0^\circ )</td>
<td>( i = 0^\circ )</td>
</tr>
</tbody>
</table>
J.6 CLASS I LANDING GEAR DESIGN

From Ch.9 of Ref.2, it is decided to choose a 30 inch tire diameter with a width of 9 inches. This tire can carry 20000 lbs.

From weight and balance calculations, longitudinal gear placement criteria were met. The is a 21° angle between the ground contact point and the aft c.g.

Fig. J.1 shows that the lateral tip-over criterion is met for a 198 inch wheel base.
LATERAL TIP OVER CRITERION TEST

FOR THE 50 PAX AIRPLANE

To meet the requirement the angle $\phi$ must be $\leq 55^\circ$.

\[ \tan 55^\circ = \frac{121}{x_1} \quad l = 84.7 \text{ in} \]
\[ x_1 = 657 - 220 = 437 \text{ in} \]
\[ \phi = \sin^{-1} \frac{l}{x_1} = \sin^{-1} \frac{84.7}{437} = 11.2^\circ \]
\[ y = (720-220) \tan 11.2^\circ \]
\[ y = 98.8 \text{ in} \]

Thus, wheel base = 198 in

FIGURE J.1 LATERAL TIP-OVER CRITERION
J.7 STABILITY AND CONTROL CALCULATIONS

The calculation of required stability derivatives are presented in this section.

- $C_{\omega w}$, Page 5.21
- $C_{\alpha H}$, Page
- $d\delta/d\alpha$, Page
- Multiple Integration, Page
- $\overline{X}_{AC_A}$, Page
- $C_{\omega V}$, Page
- $C_{n_{\beta E}}$, Page
- $C_{n_{\beta V}}$, Page
- $C_{n_{\beta}}$, Page
- $C_{n_{\sigma R}}$, Page
- $V_{MC}$, OEI, Page

J.20
WING LIFT-CURVE SLOPE

\[ S = 592 \]
\[ \Lambda_{LE} = 15^\circ = 0.2618 \text{ rad} \]
\[ A = 12 \]

From Ref. 5 , Fig. 3.12
For \( A = 12 \),
\[ K = 1 + \left[ (8.2 - 2.3 \Lambda_{LE}) - (2.2 - 1.53 \Lambda_{LE}) A \right] / 100 \]
\[ K = 1.054 \]
\[ \Lambda_{c/2} = 11.1^\circ \]
\[ C_{l\alpha} = 6.0 \text{ rad}^{-1} \quad \text{(from NLF data)} \]
\[ \beta = \sqrt{1 - M^2} = \sqrt{1 - (0.7)^2} = 0.714 \]
\[ \gamma = \frac{C_{l\alpha}}{2\pi/\beta} = 0.682 \]

Using the Polhamus Eqn. from Ch. 3 of Ref. 5:
\[ C_{l\alpha} = \frac{A}{2\pi} \left( \frac{2 + \sqrt{A^2 B^2 / X^2 (1 + \tan^2 \Lambda_{c/2}) + 4}}{K} \right) \]

\[ C_{l\alpha} = 4.72 \text{ rad}^{-1} \quad \text{M = 0.70} \]

\[ A + M = 0 \quad C_{l\alpha} = 4.79 \text{ rad}^{-1} \]
Calculation of $C_{L \alpha H}$

$A = 5 \quad \Lambda_{c/2} = 18.4^\circ \quad \Lambda_{LE} = 25^\circ$

$\lambda = .50$

$K = 1.064$

$A + M = .70 \quad B = .714 \quad \chi = .683$

$A + M = 0 \quad B = 1.0 \quad \chi = .957$

Using the Polhamus equation again:

$A + M = .70 \quad C_{L \alpha H} = 3.64 \text{ RAD}^{-1}$

$A + M = 0 \quad C_{L \alpha H} = 3.75 \text{ RAD}^{-1}$
Calculation of $\frac{de}{da}$ (using Ref. 5)

From Fig. 3.25

\[ m = \frac{230}{565} = 0.407 \quad \ell_h/c_r = 3.75 \]

\[ \tau = \frac{640}{565} = 1.13 \]

\[ \lambda = 0.4 \]

This yields \[ \frac{de}{da} = 0.325 \]

\[ 1 - \frac{de}{da} = 0.675 \]
**M. RUSSELL | ENGR. CALC. | 50 PAX 11-12-84**

**Multi-hopp Integration** for \( \Delta X_{ACB} \) (50 Pax)

\[
\frac{dM}{d\alpha} = \frac{q}{36.5} \sum_{i=1}^{N} W_i^2(x_i) \left[ \frac{d\overline{E}}{d\alpha} \right]_i \Delta x_i \text{ DEG}^{-1}
\]

<table>
<thead>
<tr>
<th>( \Delta x_i )</th>
<th>( W_i(x_i) )</th>
<th>( x_i )</th>
<th>( \frac{d\overline{E}}{d\alpha} )</th>
<th>CORRECTED ( \frac{d\overline{E}}{d\alpha} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>120</td>
<td>72</td>
<td>422</td>
<td>1.0</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>97</td>
<td>325</td>
<td>1.02</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>97</td>
<td>225</td>
<td>1.03</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>97</td>
<td>125</td>
<td>1.15</td>
</tr>
<tr>
<td>5</td>
<td>78</td>
<td>97</td>
<td>39</td>
<td>1.90</td>
</tr>
<tr>
<td>6</td>
<td>150</td>
<td>97</td>
<td>75</td>
<td>0.15</td>
</tr>
<tr>
<td>7</td>
<td>150</td>
<td>97</td>
<td>225</td>
<td>0.344</td>
</tr>
<tr>
<td>8</td>
<td>205</td>
<td>80</td>
<td>382</td>
<td>0.583</td>
</tr>
<tr>
<td>N</td>
<td>110</td>
<td>158</td>
<td>112</td>
<td></td>
</tr>
</tbody>
</table>

\( C_f = 113 \text{ in} \)

\( l_H = 442 \text{ in} \)

\( \overline{c}_H = 5.29 \text{ ft} = 63.5 \text{ in} \)

\( \overline{q} = 214 \text{ psf} \)

\( \frac{d\overline{E}}{d\alpha} = 0.325 \)

*From Ref. 5 Section 3.4.6*
\[ W_i^2(x_i) \frac{dE}{d\alpha} \Delta x_i. \]

1. \( 0.41 \times \frac{10^3}{123} \)
2. 988
3. 997
4. 1110
5. 1438
6. 162
7. 486
8. 765
9. 470

\[ \sum = 4084 \]

\[ \frac{dM}{d\alpha} = 111.9 \ \text{deg}^{-1} \]

\[ \Delta \bar{x}_{ACB} = \frac{-dM/d\alpha}{qS\bar{z}C_{Lxw}} = \frac{-111.9 \ \bar{z}}{q(592)(7.46)(0.823)} \]

\[ \Delta \bar{x}_{ACB} = -0.308 \]

\[ \bar{x}_{ACWB} = \bar{x}_{ACW} + \Delta \bar{x}_{ACWB} = 0.25 - 0.308 \]

\[ \bar{x}_{ACWB} = -0.058 \]

J.25
**Calculation of \( \bar{X}_{ACA} \)**

From Ref. 2, Ch. 11.

\[
\bar{X}_{ACA_{WB}} = -0.058 \\
C_{L\omega H} = 3.64 \text{ RAD}^{-1} \\
\frac{dE}{d\alpha} = 0.325 \\
\bar{X}_{ACA_{H}} = 6.38 \\
C_{\omega \alpha_{WB}} = 4.72 \text{ RAD}^{-1}
\]

From Eqn. 11.1 of Ref. 2

\[
\bar{X}_{ACA} = \frac{-0.058 + 3.64(1-0.325)(S_H/S)(6.38)/4.72}{1 + 3.64(1-0.325)(S_H/S)/4.72}
\]

\[
\bar{X}_{ACA} = \frac{-0.058 + 3.32(S_H/S)}{1 + 0.521(S_H/S)}
\]

<table>
<thead>
<tr>
<th>( S_H )</th>
<th>( S_H/S )</th>
<th>( \bar{X}_{ACA} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0.0845</td>
<td>0.213</td>
</tr>
<tr>
<td>100</td>
<td>0.1689</td>
<td>0.462</td>
</tr>
<tr>
<td>150</td>
<td>0.2534</td>
<td>0.692</td>
</tr>
</tbody>
</table>

**or**

\[
\bar{X}_{ACA} = 0.00479 S_H - 0.0233
\]

This is plotted in Figure J.2

J.26
C.G. SHIFT DUE TO INCREASING TAIL AREA

\[
\frac{W_{\text{emp}}}{S_{\text{emp}}} = 4.482 \text{ psf} \quad \text{from Class I Weights}
\]

\[W_v = 761.9 \text{ lbs}\]

Thus

\[W_{\text{emp}} = 4.482 S_h + 761.9\]

<table>
<thead>
<tr>
<th>(S_h)</th>
<th>(W_{\text{emp}})</th>
<th>(\bar{X}_{CGAFT})</th>
<th>(\bar{X}_{CGAFT})</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>986</td>
<td>663</td>
<td>0.235</td>
</tr>
<tr>
<td>100</td>
<td>1210</td>
<td>672</td>
<td>0.335</td>
</tr>
<tr>
<td>150</td>
<td>1434</td>
<td>680</td>
<td>0.425</td>
</tr>
<tr>
<td>200</td>
<td>1658</td>
<td>689</td>
<td>0.525</td>
</tr>
</tbody>
</table>

\[
\bar{X}_{CGAFT} = 0.00192 S_h + 0.140
\]

This is plotted in Fig. J.2
Calculation of $C_{L_{\alpha V}}$

$A = 1.4 \quad \Lambda_{LE} = 40^\circ \quad \Lambda_{c/z} = 19.9^\circ$

$K = 1 + (1.87 - 0.00233 \Lambda_{LE}) A / 100$

$K = 1.026$

Using the Polhamus equation from Figure 3.12 of Ref. 5 again:

$A + M = 0.70 \quad C_{L_{\alpha V}} = 1.87 \text{ RAD}^{-1}$

$A + M = 0 \quad C_{L_{\alpha V}} = 1.89 \text{ RAD}^{-1}$
Calculation of $C_{n_{BB}}$ (using method of Ref. 6)

\[ C_{n_{BB}} = -57.3 \; K_N \; K_{Re} \; \frac{S_{BS}}{S} \; \frac{l_B}{b} \]

\[ l_B = 94.6 \; ft \]
\[ S = 592 \; ft^2 \]
\[ b = 84.3 \; ft \]
\[ S_{BS} = 624 \; ft^2 \]
\[ x_m = 47.7 \; ft \]
\[ h_1 = 98 \; in \]
\[ h_2 = 89 \; in \]
\[ h = 98 \; in \]
\[ W = 98 \; in \]
\[ K_N = 0.001 \]
\[ R_e = \frac{\rho V l_f}{\mu} \]
\[ V = 696 \; fps \]
\[ R_e = 189 \times 10^6 \]
\[ K_{Re} = 2.08 \]

\[ C_{n_{BB}} = -0.141 \; \text{RAD}^{-1} \]

Calculation of $C_{n_{BV}}$

\[ C_{n_{BV}} = C_{Lxv} \frac{S_v}{S} \frac{x_v}{b} = 1.87 \left( \frac{S_v}{592} \right) \left( \frac{37.17}{84.3} \right) \]

\[ C_{n_{BV}} = 0.00139 \; S_v \]
Calculation of $C_{nB}$

\[ C_{nB} = C_{nB_B} + C_{nB_v} \]

Thus, \[ C_{nB} = -0.141 + 0.00139 S_v \]

This is plotted in Fig. J.3.

For a value of $C_{nB} = 0.001 \, \text{deg}^{-1}$

an \[ S_v = 143 \, \text{ft}^2 \] is required.
Estimating $C_{n_\delta R}$ for Engine-Out Calculation

$$C_{y_\delta R} = C_{L_{\alpha V}} \frac{(\alpha_\delta)}{(\alpha_\delta)_C} L_{\alpha V} (\alpha_\delta)_C K' K_b \frac{S_V}{S}$$

$$C_{L_{\alpha V}} = 1.89 \text{ rad}^{-1} \quad M = 0$$

$$(\alpha_\delta)_C = -0.70 \quad \frac{(\alpha_\delta)}{(\alpha_\delta)_C} = 1.11$$

$$K_b = 1.0 \quad K' = 0.65$$

$$C_{y_\delta R} = -0.00152 \text{ } S_V \text{ rad}^{-1}$$

$$C_{n_\delta R} = -C_{y_\delta R} \frac{x_V}{b}$$

$$= -0.00152 \text{ } S_V \left( \frac{37.17}{84.3} \right)$$

$$C_{n_\delta R} = 6.689 \times 10^{-4} \text{ } S_V$$

*From Method in Ref. 6*
ENGINE-OUT CALCULATION

From method in Ref. 2, Section 11.3

\[ \gamma_t = 5.49 \quad \text{(from 3-view)} \]

\[ P_{\text{TO REQ}} = 6000 \quad \text{(one engine)} \]

From Fig. 3.8 of Roskam’s Design Book (Part 1),

\[ T_{\text{TOe}} = 10,962 \text{ lbs} \]

\[ N_{\text{crit}} = T_{\text{TO}} \gamma_{\text{teff}} = 10962(5.49) \]

\[ N_{\text{crit}} = 60184 \text{ ft-lbs} \]

\[ N_D = 0.40 N_{\text{crit}} = 24074 \text{ ft-lbs} \]

\[ V_{mc} = 1.2 V_{sL} \]

\[ V_{sL} = 141 \text{ fps} \]

\[ V_{MC} = 169.4 \text{ fps} \]

\[ \bar{q}_{MC} = 33.9 \text{ psf} \]

\[ \delta_R = \frac{(N_{\text{crit}} + N_D)}{\bar{q}_{MC} S b C_n_{SR}} \]

\[ \delta_R = 74.17 / S_V \]

For a maximum rudder deflection of \( \delta_R = 25^\circ = 0.4363 \text{ rad} \), the required vertical tail area is:

\[ S_V = 170 \text{ ft}^2 \]
**REVISED VERTICAL TAIL TO HOLD ENGINE-OUT**

\[
S_v = 170 \text{ ft}^2 \\
b_v = 15.4 \text{ ft} \\
A_v = 1.4 \\
C_t = 7.35 \text{ ft} \\
C_r = 14.7 \text{ ft} \\
\lambda_v = 0.50 \\
\frac{C_r}{C_v} = 0.34 \\
\bar{C}_v = 11.4 \text{ ft} \\
\Lambda_{LE_v} = 40^\circ \\
\gamma_v = 5.49 \\
\lambda_v = 37.2 \text{ ft} \\
\]

J.35
3.36

J.8  CALCULATION OF CLASS I DRAG POLARS

In this section the airplane wetted area is determined. From this, the skin friction drag is approximated. Class I drag polars are constructed and compared with the preliminary drag polars from performance sizing. Table J.9 contains a wetted area breakdown.
List of components that contribute to wetted area:

Wing
Vertical Tail
Horizontal Tail
Nacelles and Pylons
Fuselage

1) Wing

\[ S_{\text{wet}} = 2 S_{\text{exp pf}} \left[ 1 + 0.25 (t/c)_r (1+\tau \lambda) / (1+\lambda) \right] \]

\[ S_{\text{exp}} = 59.2 - 80.5 = 51.5 \text{ ft}^2 \]

\[ (t/c)_r = 0.13 \quad (t/c)_t = 0.10 \quad \lambda = 0.40 \]

\[ \tau = 1.3 \]

\[ S_{\text{wet}} = 2 \left[ 51.5 \left\{ 1 + 0.25 (0.13) (1+1.3x0.4) \right\} / (1+0.4) \right] \]

\[ S_{\text{wet}} = 1059 \text{ ft}^2 \]

2) Vertical Tail

\[ S_{\text{exp}} = 170 \text{ ft}^2 \]

\[ (t/c)_r = 0.13 \quad (t/c)_t = 0.12 \quad \lambda = 0.5 \]

\[ \tau = 1.08 \]

\[ S_{\text{wet}} = 2 (170) \left[ 1 + (0.25)(0.13)(1+0.5\times1.08) / 1.5 \right] \]

\[ S_{\text{wet}} = 351 \]
3) Horizontal Tail
\[ S_{\text{exp}} = 102 \text{ ft}^2 \]
\[ \lambda = 0.5 \quad (t/c)_r = 0.12 \quad (t/c)_t = 0.10 \quad \tau = 1.2 \]
\[ S_{\text{wet}} = 2(102) \left[ 1 + 0.25(0.13)(1+1.2x0.5)/1.5 \right] \]
\[ S_{\text{wet}} = 207 \text{ ft}^2 \]

4) Nacelles
\[ S_{\text{wet}} = \pi \text{ Leng Deng} \]
\[ = \pi (108.5)(38)/144 = 90 \text{ ft}^2 \]
2 ENGINES:
\[ S_{\text{WET}} = 180 \text{ ft}^2 \]

5) Pylons
\[ \lambda = 1 \quad (t/c)_r = 0.12 \quad \tau = 1 \]
\[ S_{\text{wet}} = 2(5)(6)[1.03] = 62 \text{ ft}^2 \]
2 PYLONS:
\[ S_{\text{WET}} = 124 \text{ ft}^2 \]

6) Fuselage
\[ D_T = 8.05 \text{ ft} \quad l_T = 94.08 \text{ ft} \quad \lambda_T = 94.08/8.05 = 11.69 \]
\[ S_{\text{wet}} = \pi D_T l_T (1-2/\lambda_T)^{2/3} (1+1/\lambda_T^2) \]
\[ = \pi (8.05)(94.08)(1-2/11.69)^{2/3}(1+1/11.69^2) \]
\[ S_{\text{wet}} = 2115 \text{ ft}^2 \]

J.38
### Table 3.9 Wetted Areas of 50 PAX Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Wetted Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing</td>
<td>1059</td>
</tr>
<tr>
<td>V-Tail</td>
<td>351</td>
</tr>
<tr>
<td>H-Tail</td>
<td>207</td>
</tr>
<tr>
<td>Nacelles</td>
<td>180</td>
</tr>
<tr>
<td>Pylons</td>
<td>124</td>
</tr>
<tr>
<td>Fuselage</td>
<td>2115</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4036</strong></td>
</tr>
</tbody>
</table>

From Fig. 3.21b of Roskam's Design Book Part I, for $C_{f} = 0.0030$,

$$f = 12.1 \, \text{ft}^2$$

$$C_{D_0} = \frac{f}{S} = 12.1 / 592$$

$$C_{D_0} = \boxed{0.0204} \quad M = 0$$

Adding 0.0002 to $C_{D_0}$ for compressibility effects:

$$C_{D_0} = \boxed{0.0206} \quad M = 0.70$$

Take-off $C_{D_0}$ increment, $\Delta C_{D_0} = 0.015$

Landing $C_{D_0}$ increment
- 0.015 for gear
- 0.075 for flaps
DRAG POLARS

Take-off: \[ C_D = \frac{C_{D_0}}{\pi A e} + C_{L^2} \]
\[ C_{D_0} = 0.0204 + 0.015 = 0.0354 \]
\[ e = 0.80 \quad A = 12 \]
\[ C_D = 0.0354 + 0.0332 C_{L^2} \]

Cruise: \[ C_{D_0} = 0.0206 \]
\[ e = 0.85 \quad A = 12 \]
\[ C_D = 0.0206 + 0.0312 C_{L^2} \]

Landing: \[ C_{D_0} = 0.0204 + 0.090 = 0.110 \]
\[ e = 0.8 \quad A = 12 \]
\[ C_D = 0.110 + 0.0332 C_{L^2} \]

At cruise \[ C_L = 0.3 \]
By taking a 10% reduction in \[ C_{D_0} \] by the use of NLF:
\[ C_D = 0.0185 + 0.0312 C_{L^2} \]
\[ (L/D)_{cr} = 14.1 \]
The preliminary assumption was \[ (L/D)_{cr} = 16 \]. Thus \[ \Delta (L/D) = -1.9 \]

J.40
From initial weight sizing,

\[ \frac{\Delta W_{T0}}{\Delta (L/P)} = -994 \text{ lbs} \]

Thus \( \Delta W_{T0} = 994(1.9) = 1889 \text{ lbs} \)

\[ W^{\text{New}}_{T0} = W_{T0} + \Delta W_{T0} \]

\[ = 42057 + 1889 \]

\[ W^{\text{New}}_{T0} = 43,946 \text{ lbs} \]

This represents a 4.5% change in take-off weight. This magnitude of change does not warrant resizing.
APPENDIX K

ENGINEERING CALCULATIONS FOR THE 75 PASSENGER COMMUTER
TABLE OF CONTENTS

K.1 INTRODUCTION
K.2 INITIAL WEIGHT SIZING
K.3 INITIAL PERFORMANCE SIZING
K.4 FLAP SIZING
K.5 V-METHOD FOR EMPENNAGE SIZING
K.6 CLASS I LANDING GEAR DESIGN
K.7 STABILITY AND CONTROL CALCULATIONS
K.8 CALCULATION OF CLASS I DRAG POLAR

K.2
K.1 INTRODUCTION

THE PURPOSE OF THIS APPENDIX IS TO PRESENT THE PRELIMINARY SIZING AND CLASS I DESIGN CALCULATIONS. METHODS USED WERE TAKEN FROM REFERENCES 1 AND 2.

REFERENCES 5 AND 6 ARE USED FOR STABILITY AND CONTROL DESIGN CALCULATIONS. SECTION K.2 CONTAINS PRELIMINARY SIZING CALCULATIONS. THESE RESULTS ARE FROM XEWTOG, A COMPUTER PROGRAM AVAILABLE AT THE UNIVERSITY OF KANSAS.

SECTION K.3 CONTAINS PRELIMINARY PERFORMANCE RESULTS FROM XPRFRM.

SECTION K.4 CONTAINS CLASS I FLAP SIZING CALCULATIONS.

SECTION K.5 CONTAINS CLASS I EMPENNAGE SIZING (V-METHOD).

SECTION K.6 CONTAINS LANDING GEAR DESIGN CRITERIA.

SECTION K.7 CONTAINS STABILITY AND CONTROL CALCULATIONS.

SECTION K.8 CONTAINS THE WETTED AREA CALCULATIONS AND THE CLASS I DRAG POLARS.

K.3
K.2 INITIAL WEIGHT SIZING

Using XEWTOG, a weight sizing program which follows the method in Ch. 2 of Reference 1, the following weights and take-off weight sensitivities are for the 75 passenger airplane. See Table K.1.

The design assumptions used in the weight sizing are:

\( (L/D)_{cr} = 16 \)

\( C_p = 0.4 \text{ lbs/HP/hr} \)

\( M_p = 0.85 \)

\( V_{cr} = 442 \text{ KNOTS} \)
### TABLE K.1a: INITIAL WEIGHT SIZING RESULTS

**Weight Estimation for a Regional Propeller-Driven Aircraft**

<table>
<thead>
<tr>
<th>PHASE</th>
<th>W/L</th>
<th>CL</th>
<th>CP</th>
<th>L/D</th>
<th>ALTCD</th>
<th>PC</th>
<th>MCR</th>
<th>DR</th>
<th>W</th>
<th>D</th>
<th>P</th>
<th>PLDCAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.660</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>0.995</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>0.995</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>0.995</td>
<td>0.40</td>
<td>0.56</td>
<td>14.00</td>
<td>10.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>0.995</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>6</td>
<td>0.995</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Regression coefficients are: \( a = 0.3959 \) and \( b = 0.2647 \)

- The mission fuel fraction without reserves is 0.325
- The gross takeoff weight is 32491 pounds.
- The empty weight is 23295 pounds.
- The weight of fuel is 17258 pounds.
**TABLE K.16: SENSITIVITY RESULTS**

**EMPTY WEIGHT REDUCTION DUE TO COMPOSITES: 5.0 PER CENT**

**SENSITIVITY ANALYSIS BEGINS HERE**

**GROWTH FACTOR DUE TO PAYLOAD WEIGHT IS:**********

**THE TAKE-OFF WEIGHT TO EMPTY WEIGHT SENSITIVITY IS: 3.7**

**CHOICE NUMBER**: Cruise

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEC (LB/HR)</td>
<td>0.49</td>
</tr>
<tr>
<td>SFC (LB/HR^2)</td>
<td>0.59</td>
</tr>
<tr>
<td>PROFFICIENCY</td>
<td>0.50</td>
</tr>
<tr>
<td>L/D</td>
<td>16.7</td>
</tr>
<tr>
<td>VELOCITY (KNOTS)</td>
<td>9.2</td>
</tr>
<tr>
<td>RANGE (NM)</td>
<td>1500.0</td>
</tr>
<tr>
<td>ENDURANCE (HRS)</td>
<td>133.6</td>
</tr>
</tbody>
</table>

**THE SENSITIVITY OF GROSS TAKE-OFF WEIGHT TO THE FOLLOWING PARAMETERS IS NOW GIVEN AS THE PARTIAL DERIVATIVE OF THE GROSS TAKE-OFF WEIGHT TO THE INDICATED PARAMETER.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>DWT/O/DCJ (LB/HR/HR)</td>
<td>0.0</td>
</tr>
<tr>
<td>DWT/O/DCF (LB/HR^2/HR)</td>
<td>143193.0</td>
</tr>
<tr>
<td>DWT/O/DFP (POUNDS)</td>
<td>-2776.1</td>
</tr>
<tr>
<td>DWT/O/GLD (POUNDS)</td>
<td>-1577.7</td>
</tr>
<tr>
<td>DWT/O/OL (LB/KNOT)</td>
<td>0.0</td>
</tr>
<tr>
<td>DWT/O/DH (LB/NT MILE)</td>
<td>5.0</td>
</tr>
<tr>
<td>DWT/O/DH (LB/HR)</td>
<td>1.0</td>
</tr>
</tbody>
</table>
K.3 INITIAL PERFORMANCE SIZING

The results from XPRFRM, a performance sizing program, are presented in this section, the methods used are in Ch.3 of Reference 2. See tables K.2 through K.6.
**Table K.2**

********** TAKE-OFF SIZING **********

"FAR 25 CERTIFICATION CATEGORY"

REGIONAL TURB-PROP

PROPELLER DRIVEN

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ALTITUDE</td>
<td>---</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>10.6</td>
</tr>
<tr>
<td>40</td>
<td>19.6</td>
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<tr>
<td>60</td>
<td>34.1</td>
</tr>
<tr>
<td>80</td>
<td>4.4</td>
</tr>
<tr>
<td>100</td>
<td>4.3</td>
</tr>
</tbody>
</table>

**OUTPUT DATA**

**TABLE OF POWER LOADINGS**

<table>
<thead>
<tr>
<th>W/S</th>
<th>CLMAX</th>
<th>TO</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>1.6</td>
<td>1.8</td>
</tr>
<tr>
<td>20.0</td>
<td>21.6</td>
<td>24.2</td>
</tr>
<tr>
<td>40.0</td>
<td>34.1</td>
<td>36.7</td>
</tr>
<tr>
<td>60.0</td>
<td>4.4</td>
<td>6.1</td>
</tr>
<tr>
<td>80.0</td>
<td>4.3</td>
<td>6.1</td>
</tr>
</tbody>
</table>

**REGIONAL TURB-PROP**

**FAR 25 CERTIFICATION CATEGORY**

<table>
<thead>
<tr>
<th>GROSS TAKE-OFF WEIGHT (WTC)</th>
<th>82491.0 (LBS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LANDING TO TAKE-OFF WEIGHT RATIO</td>
<td>1.000</td>
</tr>
<tr>
<td>ALTITUDE</td>
<td>0</td>
</tr>
<tr>
<td>DENSITY</td>
<td>0.0023769 (SLUG/FT**3)</td>
</tr>
<tr>
<td>LANDING APPROACH SPEED (Vx)</td>
<td>108.0 (KTS)</td>
</tr>
<tr>
<td>LANDING FIELD LENGTH (SFL)</td>
<td>3500.0 (FEET)</td>
</tr>
</tbody>
</table>

(W/S) TO = 23.40 CLMAX(LAND)

**MAXIMUM TAKE-OFF WING LOADINGS TO MEET LANDING DISTANCE REQUIREMENT**

<table>
<thead>
<tr>
<th>CLMAX</th>
<th>MAXIMUM WING LOADING</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>2.20</td>
<td>51.49</td>
</tr>
<tr>
<td>2.40</td>
<td>56.17</td>
</tr>
<tr>
<td>2.60</td>
<td>61.85</td>
</tr>
<tr>
<td>2.80</td>
<td>67.53</td>
</tr>
<tr>
<td>3.00</td>
<td>73.21</td>
</tr>
</tbody>
</table>

**ORIGINAL PAGE IS OF POOR QUALITY**
## TABLE K.3

### SIZING TO STALL SPEED

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take-off Weight</td>
<td>62491.0 LBS</td>
</tr>
<tr>
<td>Stall Speed (Flaps-Up)</td>
<td>122.00 KTS</td>
</tr>
<tr>
<td>Stall Speed (Flaps-Down)</td>
<td>107.00 KTS</td>
</tr>
<tr>
<td>Cl Max (Flaps-Up)</td>
<td>1.56</td>
</tr>
<tr>
<td>Cl Max (Flaps-Down)</td>
<td>3.00</td>
</tr>
<tr>
<td>Wing Loading (Flaps-Up)</td>
<td>73.22   LB/FT**2</td>
</tr>
<tr>
<td>Wing Loading (Flaps-Down)</td>
<td>109.90   LB/FT**2</td>
</tr>
<tr>
<td>Max Take-Off Wing Loading</td>
<td>73.22   LB/FT**2</td>
</tr>
</tbody>
</table>

### DRAG POLAR EQUATIONS

**INPUT DATA**

- Maximum Take-Off Weight (Clean): 62491.0 LBS
- Wing Area: 500.00 FT**2
- Aspect Ratio: 12.00
- Skin Friction Coefficient: 0.002360
- Airplane Wetted Area: 8173.0 FT**2

**CALCULATED DATA**

The complete set of drag polars is:

1. Low-Speed (Clean):
   
   \[ CD = 0.0450 + 0.0312CL**2 \]
   
   \[ L/C_{max} = 12.78 \]

2. Take-Off (Landing Gear Up):
   
   \[ CD = 0.0440 + 0.0332CL**2 \]
   
   \[ L/C_{max} = 10.85 \]

3. Take-Off (Landing Gear Down):
   
   \[ CD = 0.0480 + 0.0332CL**2 \]
   
   \[ L/C_{max} = 9.47 \]

4. Landing (Landing Gear Up):
   
   \[ CD = 0.0790 + 0.0332CL**2 \]
   
   \[ L/C_{max} = 9.77 \]

5. Landing (Landing Gear Down):
   
   \[ CD = 0.0990 + 0.0332CL**2 \]
   
   \[ L/C_{max} = 8.73 \]
### TABLE K.4

**FAR 25.111 (CEI) "INITIAL CLIMB SEGMENT"**

<table>
<thead>
<tr>
<th>Wing Loading (LB/FT**2)</th>
<th>20.00</th>
<th>40.00</th>
<th>60.00</th>
<th>80.00</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td>77.76</td>
<td>54.96</td>
<td>44.89</td>
<td>36.88</td>
<td>34.77</td>
</tr>
<tr>
<td>12.00</td>
<td>81.76</td>
<td>56.96</td>
<td>44.89</td>
<td>36.88</td>
<td>34.77</td>
</tr>
<tr>
<td>13.00</td>
<td>85.76</td>
<td>58.96</td>
<td>44.89</td>
<td>36.88</td>
<td>34.77</td>
</tr>
<tr>
<td>14.00</td>
<td>92.37</td>
<td>65.34</td>
<td>53.33</td>
<td>44.16</td>
<td>41.31</td>
</tr>
</tbody>
</table>

**FAR 25.121 (CEI) "TRANSITION SEGMENT CLIMB"**

<table>
<thead>
<tr>
<th>Wing Loading (LB/FT**2)</th>
<th>20.00</th>
<th>40.00</th>
<th>60.00</th>
<th>80.00</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td>81.59</td>
<td>57.28</td>
<td>47.11</td>
<td>40.60</td>
<td>36.49</td>
</tr>
<tr>
<td>11.00</td>
<td>84.59</td>
<td>60.28</td>
<td>47.11</td>
<td>40.60</td>
<td>36.49</td>
</tr>
<tr>
<td>12.00</td>
<td>87.59</td>
<td>63.28</td>
<td>47.11</td>
<td>40.60</td>
<td>36.49</td>
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<tr>
<td>13.00</td>
<td>90.59</td>
<td>66.28</td>
<td>47.11</td>
<td>40.60</td>
<td>36.49</td>
</tr>
<tr>
<td>14.00</td>
<td>99.83</td>
<td>70.54</td>
<td>57.61</td>
<td>49.02</td>
<td>44.65</td>
</tr>
</tbody>
</table>

**FAR 25.121 (CEI) "SECOND SEGMENT CLIMB"**

<table>
<thead>
<tr>
<th>Wing Loading (LB/FT**2)</th>
<th>20.00</th>
<th>40.00</th>
<th>60.00</th>
<th>80.00</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td>70.67</td>
<td>49.97</td>
<td>40.80</td>
<td>35.33</td>
<td>31.60</td>
</tr>
<tr>
<td>11.00</td>
<td>73.16</td>
<td>52.47</td>
<td>42.26</td>
<td>37.66</td>
<td>33.90</td>
</tr>
<tr>
<td>12.00</td>
<td>75.64</td>
<td>54.96</td>
<td>44.64</td>
<td>39.96</td>
<td>36.20</td>
</tr>
<tr>
<td>13.00</td>
<td>78.12</td>
<td>57.46</td>
<td>46.54</td>
<td>41.98</td>
<td>38.50</td>
</tr>
<tr>
<td>14.00</td>
<td>82.54</td>
<td>60.36</td>
<td>47.65</td>
<td>41.27</td>
<td>40.91</td>
</tr>
</tbody>
</table>
### Table K.5

**FAR 25.121 (CEI) “EN-ROUTE CLIMB SEGMENT”**

<table>
<thead>
<tr>
<th>WING LOADING (LB/FT**²)</th>
<th>20.00</th>
<th>40.00</th>
<th>60.00</th>
<th>80.00</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPECT RATIO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td>67.78</td>
<td>47.93</td>
<td>39.13</td>
<td>33.98</td>
<td>30.31</td>
</tr>
<tr>
<td>11.00</td>
<td>69.28</td>
<td>49.46</td>
<td>40.20</td>
<td>34.69</td>
<td>31.19</td>
</tr>
<tr>
<td>12.00</td>
<td>71.92</td>
<td>50.91</td>
<td>41.45</td>
<td>35.99</td>
<td>32.16</td>
</tr>
<tr>
<td>13.00</td>
<td>75.64</td>
<td>52.38</td>
<td>42.70</td>
<td>37.29</td>
<td>33.13</td>
</tr>
<tr>
<td>14.00</td>
<td>79.41</td>
<td>53.86</td>
<td>43.95</td>
<td>38.59</td>
<td>34.10</td>
</tr>
</tbody>
</table>

**FAR 25.119 (AEQ) “LANDING CLIMB SEGMENT”**

<table>
<thead>
<tr>
<th>WING LOADING (LB/FT**²)</th>
<th>20.00</th>
<th>40.00</th>
<th>60.00</th>
<th>80.00</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPECT RATIO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td>30.32</td>
<td>21.44</td>
<td>17.51</td>
<td>15.16</td>
<td>13.56</td>
</tr>
<tr>
<td>11.00</td>
<td>31.60</td>
<td>22.35</td>
<td>18.55</td>
<td>16.66</td>
<td>14.95</td>
</tr>
<tr>
<td>12.00</td>
<td>32.96</td>
<td>23.16</td>
<td>19.51</td>
<td>17.66</td>
<td>15.95</td>
</tr>
<tr>
<td>13.00</td>
<td>34.30</td>
<td>23.96</td>
<td>20.52</td>
<td>18.66</td>
<td>15.95</td>
</tr>
<tr>
<td>14.00</td>
<td>35.75</td>
<td>24.57</td>
<td>20.06</td>
<td>17.58</td>
<td>15.54</td>
</tr>
</tbody>
</table>
### TABLE K.6

**FAR 25.121 (CEI) “GC-AROUND CR EALKED LANDING”**

**FAR 25.121 CLIMB GRADIENT (GC-ARCUNE)**

TABLE OF POWER LOADINGS REQUIRED

<table>
<thead>
<tr>
<th>Wing Loading =</th>
<th>20.00</th>
<th>40.00</th>
<th>60.00</th>
<th>80.00</th>
<th>100.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>(lb/ft<strong>2</strong>)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td>32.5</td>
<td>38.4</td>
<td>32.6</td>
<td>30.5</td>
<td>26.45</td>
</tr>
<tr>
<td>12.00</td>
<td>35.1</td>
<td>40.4</td>
<td>35.6</td>
<td>32.9</td>
<td>29.37</td>
</tr>
<tr>
<td>15.00</td>
<td>39.7</td>
<td>45.4</td>
<td>39.6</td>
<td>37.5</td>
<td>34.75</td>
</tr>
<tr>
<td>14.00</td>
<td>58.2</td>
<td>51.2</td>
<td>41.4</td>
<td>36.5</td>
<td>31.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Altitude</th>
<th>33000 (FEET)</th>
<th>33000 (SLUG/FT**2*)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oswald's Efficiency Factor (g)</td>
<td>1.20</td>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td>Propeller Efficiency</td>
<td>0.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zero Lift Drag Coefficient</td>
<td>0.0490</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Take-Off Weight</td>
<td>62491.0 (LBS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specified Maneuvering Weight</td>
<td>50000.0 (LBS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity</td>
<td>250.0 (KTS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mach Number</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Load Factor</td>
<td>7.00 (g/s)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Minimum Wing Loading**

Minimum Wing Loading

20.00 (lb/ft**2**)

Maximum Wing Loading

100.00 (lb/ft**2**)

\[(W/P) = (W/S)/0.3C + 2978.35(W/S)\]

Power Loadings Necessary to Meet the Cruise Speed Requirements

<table>
<thead>
<tr>
<th>(W/S) Actual</th>
<th>(W/S) Takeoff</th>
<th>(W/P) Actual</th>
<th>(W/P) Takeoff In Flight</th>
<th>(W/P) Takeoff Static</th>
</tr>
</thead>
<tbody>
<tr>
<td>(psf)</td>
<td>(psf)</td>
<td>(lb/psf)</td>
<td>(lb/psf)</td>
<td>(lb/psf)</td>
</tr>
<tr>
<td>17.00</td>
<td>20.00</td>
<td>2.10</td>
<td>2.67</td>
<td>1.24</td>
</tr>
<tr>
<td>34.00</td>
<td>40.00</td>
<td>4.26</td>
<td>4.94</td>
<td>3.71</td>
</tr>
<tr>
<td>51.00</td>
<td>60.00</td>
<td>6.34</td>
<td>7.44</td>
<td>4.94</td>
</tr>
<tr>
<td>68.00</td>
<td>80.00</td>
<td>8.41</td>
<td>9.69</td>
<td>6.18</td>
</tr>
<tr>
<td>85.00</td>
<td>100.00</td>
<td>10.51</td>
<td>12.36</td>
<td></td>
</tr>
</tbody>
</table>

K. 12
K.4 FLAP SIZING

Using a method in Ch. 7 of Ref. 2, it was determined that the following flap geometry would supply the incremental lift necessary for take-off and landing. See Table K.7. The design calculations follow.

**Table K.7 75 Pax Flap Geometry**

Trailing Edge Fowler Flaps

- \( \frac{c_f}{c} = 0.25 \)
- \( \frac{S_{nf}}{S} \cong 0.80 \)
- \( \frac{b_f}{b} \cong 0.80 \)
- \( \delta_f = 30^\circ \)
FLAP SIZING: 75 PAX

\[
\tan \Lambda_{.25\%} = \tan \Lambda_{LE} - \frac{4}{12}[(.25)(.429)]
\]
\[
\tan \Lambda_{.25\%} = .268 - .036
\]
\[
\Lambda_{.25\%} = 13^\circ
\]

ASSUME FROM MATCHING GRAPH:

\[
C_{l_{\text{max clean}}} = 1.40
\]

\[
C_{l_{\text{max w}}} = 1.05 (C_{l_{\text{max clean}}}) = 1.05(1.40)
\]

\[
C_{l_{\text{max w}}} = 1.47
\]

\[
C_{l_{\text{max w}} \text{ unswept}} = \frac{1.47}{\cos 13^\circ}
\]

\[
C_{l_{\text{max w}} \text{ unswept}} = 1.51
\]

\[
C_{l_{\text{max w}}} = 0.95(1.5 + 1.5) / 2
\]

\[
C_{l_{\text{max w}}} = 1.43
\]

\[
\Delta C_{l_{\text{max l}}} = 1.05 (C_{l_{\text{max l}}} - C_{l_{\text{max w}}})
\]

\[
\Delta C_{l_{\text{max l}}} = 1.05 (3.00 - 1.43)
\]

\[
\Delta C_{l_{\text{max l}}} = 1.65
\]

\[
\Delta C\text{\text{max}} = \Delta C_{l_{\text{max}}} (S/\text{Swtf}) K_L
\]

\[
K_{L14}
\]
\[ K_L = (1 - 0.08 \cos^2 13^\circ) \cos^{34} 13^\circ \]

\[ K_L = 0.906 \]

**Assume:** \[ C_f/l = 0.25 \]
\[ \delta_f = 30^\circ \]

\[ K = 0.96 \]
\[ \Delta C_l = \left( \frac{1}{0.96} \right) \Delta C_l_{\text{max}} \]

<table>
<thead>
<tr>
<th>( \text{Swf}/S )</th>
<th>( S/\text{Swf} )</th>
<th>( \Delta C_l_{\text{max}} )</th>
<th>( \Delta C_l )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>2.50</td>
<td>3.74</td>
<td>3.90</td>
</tr>
<tr>
<td>0.5</td>
<td>2.00</td>
<td>2.99</td>
<td>3.11</td>
</tr>
<tr>
<td>0.6</td>
<td>1.67</td>
<td>2.50</td>
<td>2.60</td>
</tr>
<tr>
<td>0.7</td>
<td>1.43</td>
<td>2.14</td>
<td>2.23</td>
</tr>
<tr>
<td>0.8</td>
<td>1.25</td>
<td>1.87</td>
<td>1.95</td>
</tr>
<tr>
<td>0.9</td>
<td>1.11</td>
<td>1.66</td>
<td>1.73</td>
</tr>
</tbody>
</table>

**For Fowler Flaps:**

**Assume:** \( C_{l_{\alpha}} = 21\pi \)

\[ C_{l_{\alpha f}} = 21\pi \left( 1 + 0.25 \right) = 7.85 \]

\[ \Delta C_l = C_{l_{\alpha f}} \alpha \delta_f \delta_f = (7.85)(0.47)(0.52) \]

\[ \Delta C_l = 1.93 \]

\[ \therefore \text{Swf}/S \approx 0.8 \]

\[ K.15 \]
K.5 \( \overline{V} \)-METHOD FOR EMPENNAGE SIZING

The 75 Pax commuter empennage is of the conventional T-tail type. Table K.8 contains the geometry of the empennage. From tables 8.6a and 8.6b, average values of \( \overline{V_h} \) and \( \overline{V_v} \) were obtained.
Empennage Sizing 75 Pax:

The following values were determined by comparison with MD-80, B727-200, Bae 146-200 and the Fokker F28.

\[ l_f = 108.42 \text{ ft.} \]
\[ d_f = 8.05 \text{ ft.} \]
\[ X_v = 45.5 \text{ ft.} \]
\[ X_h = 55.3 \text{ ft.} \]
\[ \bar{V}_h = 1.08 \]
\[ \bar{V}_v = 0.083 \]
\[ S_h = 241.8 \text{ ft}^2 \]
\[ S_v = 255.5 \text{ ft}^2 \]
\[ S_e = 87.0 \text{ ft}^2 \]
\[ S_r = 86.9 \text{ ft}^2 \]

Elevator Chord Root/Tip (fraction of \( C_h \))

\[ 0.39/0.45 \]

Rudder Chord Root/Tip (fraction of \( C_v \))

\[ 0.35/0.32 \]
**HORIZONTAL TAIL:**

- \( \Gamma = 0^\circ \)
- \( i_h = \text{variable} \)
- \( AR = 5.3 \)
- \( \lambda_{25\%} = 22^\circ \)
- \( \lambda_h = 0.35 \)
- \( C_r = 11.01 \text{ ft} \)
- \( C_t = 3.85 \text{ ft} \)
- \( b = 32.53 \text{ ft} \)

*TABLE K.8*

**VERTICAL TAIL:**

- \( \Gamma = 90^\circ \)
- \( i_v = 0 \)
- \( AR = 1.4 \)
- \( \lambda_{25\%} = 42^\circ \)
- \( \lambda_v = 0.60 \)
- \( C_r = 19.64 \text{ ft} \)
- \( C_t = 11.79 \text{ ft} \)
- \( b = 16.26 \text{ ft} \)
K.6 CLASS I LANDING GEAR DESIGN

From CH.9 in Reference 2 it was decided to choose a 30" diameter tire 9" wide. This tire can carry 20,000 LBS.

From weight and balance calculations longitudinal gear placement criterion were met. There is a 15° between ground contact point and aft C.G.

Figure K.1 shows that the lateral tip-over criterion is met for a 206" wheel base.
1.) TIP-OVER CRITERIA:

For tricycle aircraft: The main gear must be behind the aft C.G. location. The usual relationship between the aft C.G. location and the main landing gear is 15°.

In the figure, it is clear that the main gear is located behind the aft C.G. location. Also, it is clear that the aft C.G. location is located forward of the 15° angle with reference to the main gear. The location of the gear satisfies the longitudinal tip-over criterion.

2.) LATERAL TIP-OVER CRITERIA

The lateral tip-over is dictated by the angle θ.
CLASS I METHOD FOR LANDING GEAR SIZING AND DISPOSITION

STEP 9.1 DECIDE WHICH LANDING GEAR SYSTEM TO USE:

RETRACTABLE

STEP 9.2 DECIDE ON THE OVERALL LANDING GEAR CONFIGURATION:

CONVENTIONAL (TRICYCLE)

STEP 9.3 PROCEED TO CHAPTER 10 AND PREPARE A ROUGH WEIGHT AND BALANCE STATEMENT FOR AN ASSUMED DISPOSITION OF THE LANDING GEAR

SEE FIGURE

STEP 9.4 DECIDE ON A PRELIMINARY LANDING GEAR STRUT DISPOSITION AND SKETCH THE PROPOSED STRUT DISPOSITION IN THE GENERAL ARRANGEMENT DRAWING OF STEP 10.2 (CHAPTER 10).

SEE FIGURE
For $\gamma = 45^\circ$, $B = 150''$

$\gamma = 50^\circ$, $B = 124''$

$\gamma = 55^\circ$, $B = 103''$

**NOTE**

$\gamma \leq 55^\circ$

**Figure K.1**
K.7 Stability and Control Calculations

Calculation of required stability and control derivatives are presented in this section.
<table>
<thead>
<tr>
<th>Body Segment</th>
<th>( W_f )</th>
<th>( X_i )</th>
<th>( W_f^2 ) (( X_i ))</th>
<th>( \Delta X_i )</th>
<th>( \Delta )dx</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (cockpit)</td>
<td>70</td>
<td>595</td>
<td>34.03</td>
<td>8.33</td>
<td>1.03</td>
</tr>
<tr>
<td>2</td>
<td>96</td>
<td>495</td>
<td>64.0</td>
<td>8.33</td>
<td>1.03</td>
</tr>
<tr>
<td>3</td>
<td>96</td>
<td>395</td>
<td>64.0</td>
<td>8.33</td>
<td>1.06</td>
</tr>
<tr>
<td>4</td>
<td>96</td>
<td>295</td>
<td>64.0</td>
<td>8.33</td>
<td>1.13</td>
</tr>
<tr>
<td>5</td>
<td>96</td>
<td>195</td>
<td>64.0</td>
<td>8.33</td>
<td>1.20</td>
</tr>
<tr>
<td>Wing</td>
<td>6</td>
<td>72.5</td>
<td>64.0</td>
<td>12.06</td>
<td>1.89</td>
</tr>
<tr>
<td>7</td>
<td>96</td>
<td>91</td>
<td>64.0</td>
<td>15.17</td>
<td>1.44</td>
</tr>
<tr>
<td>8</td>
<td>94</td>
<td>232</td>
<td>61.36</td>
<td>8.33</td>
<td>0.36</td>
</tr>
<tr>
<td>9</td>
<td>78</td>
<td>332</td>
<td>42.25</td>
<td>8.33</td>
<td>0.52</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
<td>439.5</td>
<td>17.36</td>
<td>9.58</td>
<td>0.69</td>
</tr>
<tr>
<td>Engine ( E_1 )</td>
<td>30</td>
<td>434</td>
<td>6.25</td>
<td>10.92</td>
<td>0.68</td>
</tr>
<tr>
<td>Engine ( E_2 )</td>
<td>30</td>
<td>434</td>
<td>6.25</td>
<td>10.92</td>
<td>0.68</td>
</tr>
</tbody>
</table>
$\phi = 11.12^\circ$
$\phi = 0.71414$
$K = 0.682$
$K = 1.05439$

$C_{L_{aw}} = 4.709 \text{ rad}^{-1} = 0.0822 \quad \text{(Ref. 5)}$

\[
\frac{dE}{dx} C_{L_{aw}} = \frac{dE}{dx} C_{L_{ax}} = 0.08 \times 1.0274
\]

$C_f = 172.0^\circ$
$x = 1.00$
$\lambda = 0.33$
$\lambda = 0.33$
$\frac{dE}{dx} = 0.185$
$m = 0.33$
$r = 0.93$
$\frac{dE}{dx} = 0.180 \times 0.975$

$l_4 = 518''$
$1 - \frac{dE}{dx} = 0.82$

$\frac{dm}{dx} = \frac{132.37}{\text{g}}$

$\Delta X_{AC} = \frac{0.13}{\text{g}}$

K.25
$A_r = 4.368$
$\lambda_{25e} = 22^\circ$
$\lambda_{LE} = 27.2^\circ$
$\lambda_{1/2} = 16.4^\circ$

$K = 1.06464$
$\beta = 0.71414$
$K = 0.682$

$C_{L\alpha_H} = 3.514 \text{ rad}^{-1}$
\[ X_{ac_H} = 614.0'' \]
\[ \overline{X}_{ac_H} = 4.87 \]
\[ X_{ac_A} = 0.12 + \left( \frac{3.514}{4.709} \right) \frac{S_H}{5} (4.87)(0.82) \]
\[ \frac{1 + \frac{3.514}{4.709}}{S_H} \frac{S_H}{5} (0.82) \]
\[ X_{ac_A} = 0.12 + 0.00253 S_H \frac{S_H}{1 + 0.000519 S_H} \]

\[ \overline{X}_{ac_A} \]
\[ 0.650 \]
\[ 0.567 \]
\[ 0.463 \]
\[ 0.355 \]
\[ 0.240 \]

\[ S_H \]
\[ 241.8 \]
\[ 200 \]
\[ 150 \]
\[ 100 \]
\[ 50 \]

From Figure K2 with \( SM = -0.05 \)

\[ S_H = 134 \text{ ft}^2 \]
\[ C_{n\theta} = -57.3 \cdot K_n \cdot K_{p\theta} \cdot \frac{S_{b\theta}}{S} \cdot \frac{L}{b} \]

\[ X_m = 746 \text{ in} \]
\[ \bar{L} = 1.301 \text{ in} \]
\[ \frac{X_m}{\bar{L}} = 0.573 \]
\[ S_{b\theta} = 734.5 \text{ ft}^2 \]
\[ K_n = 0.000875 \]
\[ K_{p\theta} = 2.1 \]
\[ \mu = 3.106 \times 10^{-7} \text{ lb sec/ft}^2 \]

\[ \therefore C_{n\theta} = -0.0599 \]

**Determine \( C_{l\alpha v} \) from Polhamus:**

\[ R_v = 1.04 \]
\[ \alpha_{LE} = 49^\circ \]
\[ \alpha_{c/2} = 33.8^\circ \]
\[ K_v = 1.0194 \]

\[ \therefore C_{l\alpha v} = 1.426 \]

\[ C_{n\theta} = C_{n\theta} + C_{l\alpha v} \left( \frac{S_v}{S} \right) \left( \frac{X_v}{b} \right) \]

\[ C_{n\theta} = -0.0599 + 0.0003902 \cdot S_v \]

\[ K.29 \]
\[ \begin{array}{|c|c|c|}
\hline
S_v & C_{n_{\theta}} \text{ rad}^{-1} & C_{n_{\theta}} \text{ deg}^{-1} \\
\hline
255 & 0.0396 & 0.00069 \\
200 & 0.01814 & 0.00032 \\
270 & 0.04545 & 0.00079 \\
300 & 0.05716 & 0.00100 \\
310 & 0.06106 & 0.00107 \\
\hline
\end{array} \]

From \textit{S+C handbook} of Reference 6: 
\( (\alpha d_{\theta})_2 = -0.71 \)

\( \frac{(\alpha d_{\theta})_2}{(\alpha d_{\theta})_1} = 1.02 \)

For \( \delta_r = 25^\circ \) and \( C_r/c = 0.35 \):
\( \kappa_b = 1.0 \)
\( k' = 0.65 \)

\[ C_{y_{\delta r}} = C_{l\alpha \gamma} \frac{(\alpha d_{\theta})_2}{(\alpha d_{\theta})_1} (\alpha \delta)_c \ k' \ k_b \ \frac{S_v}{S} \]

\[ C_{n \delta r} = -C_{y_{\delta r}} \ \frac{S_v}{b} \]

\[ \therefore C_{n \delta r} = 0.000176 \ S_v \]

\( C_{n \delta r} \) needed for 25 deg rudder deflection:
\( 25^\circ = 0.06386 \ \text{rad} \)

\[ 0.06386 = 0.000176 \ S_v \]
\[ \therefore S_v = 363 \ \text{ft}^2 \]
K.8 CALCULATION OF CLASS I DRAG POLARS

This section computes the airplane wetted area, and estimates skin friction drag. Class I drag polars are constructed and compared with the polars computed for the performance sizing. Table K.9 contains a wetted area breakdown.
1) **WING:**
   \[ S_{\text{exp}} = 1071.0 \, \text{ft}^2 \]
   \[ \tau = \frac{t}{c} = 0.13 \]
   \[ \alpha = 1 \]
   \[ \lambda = 0.4 \]
   \[ S_{\text{wet}} = 2212.0 \, \text{ft}^2 \]

2) **HORIZONTAL TAIL:**
   \[ \lambda = 0.35 \]
   \[ \tau = 1.0 \]
   \[ S_{\text{wet}} = 277 \, \text{ft}^2 \]

3) **VERTICAL TAIL:**
   \[ \lambda = 0.60 \]
   \[ \tau = 1.0 \]
   \[ S_{\text{wet}} = 750 \, \text{ft}^2 \]
FUSELAGE:

\[ \lambda_f = 13.55 \]
\[ D_f = 8.0 \text{ ft} \]
\[ L_f = 108.4 \text{ ft} \]
\[ S_{\text{fret}} = 2463 \text{ ft}^2 \]

ENGINES:

\[ l = 150.1 \text{ in} \]
\[ D = 37.3 \text{ in} \]
\[ S_{\text{fret}} = 248 \text{ ft}^2 \quad (2 \text{ NACELLES}) \]

PYLONS:

\[ \lambda = 1.0 \]
\[ (t/c) = 0.12 \]
\[ C = 1.0 \]
\[ S_{\text{fret}} = 124 \text{ ft}^2 \quad (2 \text{ PYLONS}) \]
TOTAL BY SUMMING ALL INDIVIDUAL CONTRIBUTIONS IS:

\[ S_{net} = 6,074 \text{ ft}^2 \]

FROM FIGURE 3.2.1

\[ f = 14.88 \text{ ft}^2 \]

\[ C_{D0} = \frac{f}{s} = 0.0126 \]

\[ \Delta C_{D0_{ TO}} = 0.015 \]

\[ \Delta C_{D0_{L}} = 0.075 \]

\[ \Delta C_{D0_{gear}} = 0.020 \]

DRAG POLARS

TAKE-OFF "GEAR-UP"

\[ AR = 12 \quad e = 0.80 \]

\[ C_D = 0.0276 + 0.0332 C_{L}^2 \]

TAKE-OFF "GEAR-DOWN"

\[ AR = 12 \quad e = 0.80 \]

\[ C_D = 0.0476 + 0.0332 C_{L}^2 \]
CLEAN "LOW-SPEED"
\[ AR = 12 \quad c = 0.85 \]
\[ C_D = 0.0126 + 0.0312 \, C_L^2 \]

LANDING "GEAR-UP"
\[ AR = 12 \quad c = 0.80 \]
\[ C_D = 0.0876 + 0.0332 \, C_L^2 \]

LANDING "GEAR-DOWN"
\[ AR = 12 \quad c = 0.80 \]
\[ C_D = 0.1076 + 0.0332 \, C_L^2 \]

\[ C_L_{\text{CRUISE}} = 0.3 \]
\[ (L/D)_{CR} = 19.47 \]

FROM INITIAL WEIGHT SIZING AN
\[ (L/D)_{CR} = 16.0 \] WAS ASSUMED AND
\[ \frac{\partial W_T}{\partial L/D} = -3579.7 \text{ lbs.} \]

\[ \Delta L/D = \text{CLASS I} \quad L/D - \text{INITIAL L/D} \]
\[ \Delta L/D = 19.47 - 16.0 \]
\[ \Delta L/D = 3.47 \]

\[ \Delta W_T = \frac{\partial W_T}{\partial L/D} \cdot \Delta L/D = (-3579.7 \times 3.47) \]
\[ \Delta W_T = -12,422 \text{ lbs (DECREASE)} \]

k.36
\[ W_{T_{0\text{-new}}} = 82,491 \text{ LBS.} - 12,422 \text{ LBS} \]

\[ W_{T_{0\text{new}}} = 70,069 \text{ LBS.} \]
APPENDIX L

ENGINEERING CALCULATIONS FOR THE 100 PASSENGER COMMUTER

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<td>L.3 PRELIMINARY PERFORMANCE SIZING</td>
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</table>
L.1 INTRODUCTION

The purpose of this appendix is to present the preliminary sizing and class I design calculations. Methods used were taken from References (1) and (2). References (5) and (6) are used for stability and control considerations.

Section L.2 contains preliminary weight sizing calculations. These results were obtained using the methods presented in Reference (1).

Section L.3 contains preliminary performance sizing calculations. These results were obtained using the methods presented in Reference (1).

Section L.4 contains class I flap sizing calculations using the methods presented in Reference (2).

Section L.5 contains class I empennage sizing using the \( V \)-bar method presented in Reference (2).

Section L.6 contains landing gear design criteria using the methods of Reference (2).

Section L.7 contains the stability and control calculations using the methods presented in Reference (2).

Section L.8 contains the class I drag polars calculated using the methods presented in Reference (2).
L.2 INITIAL WEIGHT SIZING

Using the methods presented in Reference (1) the weights and weight sensitivities for the 100 passenger airplane were calculated and are presented in Table L.1.

The design assumptions used in the weight sizing were:

\[(L/D)cr = 16\]
\[C_p = 0.4 \text{ lbs/hp/hr}\]
\[N_p = 0.85\]
\[V_{cr} = 442 \text{ knots}\]
DESIGN AIRPLANE: 100 PASSENGER COMMUTER
(TYPE ½ AIRPLANE)

ASSUME:

\[ \text{RANGE} = 1500 \text{ nm} \]

\[ \frac{L}{D} = 1.6 \]

\[ C_D = 0.4 \]

\[ \eta_p = 0.85 \]

\[ W_{f,\text{f.o.}} = 0.005 W_{\text{TO}} \]

\[ W_{f,\text{res}} = 0.25 W_{f,\text{used}} \]

\[ h = 30,000 \text{ ft} \]

\[ M = 0.75 \]

FUEL FRACTION VALUES FROM TABLE 2.1.
CLIMB: 3000 fpm

Cruise Velocity:

FROM FIG. 11 OF LAN & ROSKAM: AERODYNAMICS,

\[ V_a = 994.7 \text{ fps} \quad \text{at} \quad 30,000 \text{ ft} \]

\[ M = \frac{V_{cr}}{V_a} \Rightarrow V_{cr} = 0.75 \times (994.7) \]

\[ V_{cr} = 746 \text{ fps} \]

CONVERTING TO KNOTS (REF. PG. 528),

\[ V_{cr} = 746 \text{ fps} \times 0.5921 = 442 \text{ kts} \]

ESTIMATING \( W_{\text{TO}}, W_{E}, W_{F} \):

STEP 1: MISSION PAYLOAD WEIGHT, \( W_{PL} \), AND CREW WEIGHT, \( W_{\text{crew}} \).

FROM THE GIVEN SPECIFICATION:

PASSENGERS:

\[ 100 \times (175 \text{ lbs} + 30 \text{ lbs}) \]

\[ 100 \times 205 \]

\[ W_{PL} = 20,500 \text{ lbs} \]

CREW:

\[ 4 \times (175 + 30) \]

\[ 4 \times 205 \]

\[ W_{\text{crew}} = 820 \text{ lbs} \]
STEP 2: GUESS VALUE OF TAKE-OFF WEIGHT, W\textsubscript{T0}.

FROM JANE'S, 1974-75, SIMILAR PLANES WERE FOUND AS FOLLOWS:

<table>
<thead>
<tr>
<th>AIRPLANE</th>
<th>W\textsubscript{PL} (lbs)</th>
<th>W\textsubscript{T0} (lbs)</th>
<th>V\textsubscript{C\textsubscript{RMAX}} (kts)</th>
<th>RANGE (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEROSPATIALE BE-210</td>
<td>29,100</td>
<td>127,870</td>
<td>445</td>
<td>1870</td>
</tr>
<tr>
<td>CARAVELLE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HAWKER - SIDDELEY</td>
<td>23,015</td>
<td>87,500</td>
<td>422</td>
<td>1730</td>
</tr>
<tr>
<td>146-200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCDONNELL - DOUGLAS DC-9, SERIES 10, MODEL 15</td>
<td>21,381</td>
<td>90,700</td>
<td>487</td>
<td>964</td>
</tr>
<tr>
<td>MCDONNELL - DOUGLAS DC-9, SERIES 20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TUPOLEV TU-134A</td>
<td>18,000</td>
<td>103,600</td>
<td>469</td>
<td>1293</td>
</tr>
<tr>
<td>DESIGN PLANE</td>
<td>20,500</td>
<td>?</td>
<td>442</td>
<td>1500</td>
</tr>
</tbody>
</table>

A REASONABLE ESTIMATE OF TAKE-OFF WEIGHT WOULD BE: \( W\textsubscript{T0} = 96,000 \) lbs.

STEP 3: DETERMINE MISSION FUEL WEIGHT, W\textsubscript{F}.

\[ W\textsubscript{F} = W\textsubscript{FUSED} + W\textsubscript{RES} \]

FROM SPEC: \( W\textsubscript{RES} = 0.25 W\textsubscript{FUSED} \)

\[ W\textsubscript{F} = 1.25 W\textsubscript{FUSED} \]

MISSION PROFILE:

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DEF. OF STAGES:
1) ENGINE START, WARM-UP
2) TAXI
3) TAKE-OFF
4) CLIMB AND ACCELERATE
5) CRUISE
6) DESCENT
7) LANDING, TAXI, SHUTDOWN
STEP 3: (cont.)

PHASE 1: BEGIN WEIGHT: \( W_0 \)
(ENGINE START) END WEIGHT: \( W_1 \)

FROM TABLE 2.1: \( \frac{W_1}{W_0} = 0.990 \)

PHASE 2: BEGIN WEIGHT: \( W_1 \)
(TAXI) END WEIGHT: \( W_2 \)

FROM TABLE 2.1: \( \frac{W_2}{W_1} = 0.995 \)

PHASE 3: BEGIN WEIGHT: \( W_2 \)
(TAKE-OFF) END WEIGHT: \( W_3 \)

FROM TABLE 2.1: \( \frac{W_3}{W_2} = 0.995 \)

PHASE 4: BEGIN WEIGHT: \( W_3 \)
(CLIMB) END WEIGHT: \( W_4 \)

FROM FIG 2.2: \( \frac{W_4}{W_3} = 0.970 \)

USING BREGUET'S ENDURANCE EQUATION, P. 13:

\[
E_{cl} = 375 \left( \frac{1}{V_{cl}} \right) \left( \frac{T_0}{C_p} \right) c_1 \left( \frac{1}{v_{th}} \right) c_1 \ln \left( \frac{W_3}{W_4} \right)
\]

\[
V_{cl} = 3000 \text{ fpm} \left( \frac{60 \text{ min}}{1 \text{ hr}} \right) \left( \frac{1 \text{ mile}}{5280 \text{ ft}} \right)
\]

\[
V_{cl} = 34.1 \text{ mph}
\]

\[
E_{cl} = \frac{39,000 \ \text{ft}}{3000 \ \text{fpm}} = 10 \text{ min} = \frac{1}{6} \text{ hr}
\]

\[
\ln \left( \frac{W_3}{W_4} \right) = \frac{E_{cl} V_{cl}}{375} \left( \frac{T_0}{C_p} \right) c_1 \left( \frac{1}{v_{th}} \right) c_1
\]

\[
\ln \left( \frac{W_3}{W_4} \right) = \left( \frac{1}{6} \right) (34.1 \text{ mph}) \left( \frac{0.4}{0.95} \right) \left( \frac{1}{16} \right) = 4.16 \times 10^{-4}
\]

\[
\frac{W_4}{W_3} = 0.999 \quad \text{DOESN'T SEEM CORRECT;}
\]

WILL USE ABOVE FRACTION.
STEP 3: (cont.)

PHASE 5: \( \text{BEGIN WEIGHT: } W_4 \)
\( \text{END WEIGHT: } W_5 \)

**ESTIMATE \( \frac{W_5}{W_4} \) FROM BREGUET’S RANGE EQUATION, p. 15, eqn. 2.9.**

\[
R_{cr} = 375 \left( \frac{n C_p}{c} \right) _{cr} \left( \frac{V}{V_o} \right) _{cr} \ln \left( \frac{W_4}{W_5} \right) = 1500 \text{ nm} \left( \frac{0.076 \text{ ft}}{1 \text{ nm}} \right) \left( \frac{1 \text{ sm}}{5280 \text{ ft}} \right)
\]

**R_{cr} = 1726 \text{ sm}**

\[
\left( \frac{1726 \text{ sm}}{375} \right) = (0.35)(0.1) \ln \left( \frac{W_4}{W_5} \right)
\]

\[
\ln \left( \frac{W_4}{W_5} \right) = \left( \frac{1726}{375} \right) = 0.1354
\]

\[
\frac{W_4}{W_5} = 1.145 \quad \Rightarrow \quad \frac{W_5}{W_4} = 0.8734
\]

\[
\frac{W_5}{W_4} = 0.873
\]

PHASE 6: \( \text{BEGIN WEIGHT: } W_5 \)
\( \text{END WEIGHT: } W_6 \)

**FROM TABLE 2.1: \( \frac{W_6}{W_5} = 0.985 \)**

PHASE 7: \( \text{BEGIN WEIGHT: } W_6 \)
\( \text{END WEIGHT: } W_7 \)
\( \text{(LANDING, TAXI, SHUTDOWN)} \)

**FROM TABLE 2.1:**

\[
\frac{W_7}{W_6} = 0.995
\]

MISSION FUEL FRACTION \( M_{ff} \):

\[
M_{ff} = \frac{W_1}{W_0} \cdot \frac{W_2}{W_1} \cdot \frac{W_3}{W_2} \cdot \frac{W_4}{W_3} \cdot \frac{W_5}{W_4} \cdot \frac{W_6}{W_5} \cdot \frac{W_7}{W_6}
\]

\[
= (0.990)(0.995)(0.995)(0.970)(0.873)(0.985)(0.995)
\]

\[
M_{ff} = 0.813
\]
STEP 3: (cont)

\[ W_{\text{Fused}} = (1 - M_{\text{FF}}) W_{\text{T0}} \]
\[ = (1 - 0.813) W_{\text{T0}} \]
\[ W_{\text{Fused}} = 0.187 W_{\text{T0}} \]

MISSION FUEL WEIGHT:

\[ W_{\text{F}} = W_{\text{Fused}} + W_{\text{Fres}} \]
\[ = W_{\text{Fused}} + 0.25 W_{\text{Fused}} \]
\[ = 1.25 W_{\text{Fused}} \]
\[ W_{\text{F}} = 1.25 (0.187 W_{\text{T0}}) \]
\[ W_{\text{F}} = 0.234 W_{\text{T0}} \]

STEP 4: CALCULATE A TENTATIVE VALUE FOR \( W_{\text{OE}} \) FROM:

\[ W_{\text{OE, Tent}} = W_{\text{T0, Guess}} - W_{\text{F}} - W_{\text{PL}} \]
\[ W_{\text{OE, Tent}} = 96,000 \text{ lbs} - 0.234 (96,000 \text{ lbs}) \]
\[ - 20,500 \text{ lbs} \]
\[ W_{\text{OE, Tent}} = 53,036 \text{ lbs} \]

STEP 5: CALCULATE A TENTATIVE VALUE FOR \( W_{\text{E}} \) AS:

\[ W_{\text{E, Tent}} = W_{\text{OE, Tent}} - W_{\text{F0}} - W_{\text{crew}} \]
\[ = 53,036 \text{ lbs} - (0.055 W_{\text{T0}}) - 820 \text{ lbs} \]
\[ = 52,216 - 0.055 (96,000) \]
\[ W_{\text{E, Tent}} = 51,736 \text{ lbs} \]

STEP 6: FIND THE ALLOWABLE VALUE OF \( W_{\text{E}} \) FROM SECTION 2.5.

FROM FIG. 2.8, PG. 24, AT \( W_{\text{T0}} = 96,000 \text{ lbs}, \)

\[ W_{\text{E, All}} = 55,000 \text{ lbs}. \]

NOT WITHIN THE ALLOWABLE TOLERANCE.
Due to the large error between the predicted empty weight and the allowable empty weight, a new value for \( W_e \) and \( W_{to} \) are calculated using the empty weight equation from Reference (1):

\[
W_e = \frac{W_{cmp}}{W_{metal}} \times \log_{10} \left( \frac{\log_{10} W_{to} - A}{B} \right)
\]

From Table 2.15 of Reference (1):

\[
A = 0.3774 \\
B = 0.9647
\]

\[
W_e = 0.90 \times \log_{10} \left( \frac{\log_{10} W_{to} - 0.3774}{0.9647} \right)
\]

<table>
<thead>
<tr>
<th>( W_{to} ) (lbs)</th>
<th>( W_e ) (allowable) (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80,000</td>
<td>47,653</td>
</tr>
<tr>
<td>90,000</td>
<td>49,953</td>
</tr>
<tr>
<td>95,000</td>
<td>52,832</td>
</tr>
<tr>
<td>96,000</td>
<td>53,408</td>
</tr>
<tr>
<td>98,000</td>
<td>54,563</td>
</tr>
<tr>
<td>100,000</td>
<td>55,717</td>
</tr>
<tr>
<td>105,000</td>
<td>58,608</td>
</tr>
</tbody>
</table>

Original page is of poor quality
Using the value of \( W_{t0} = 105,000 \text{ lb} \) in the fuel fraction equations calculated previously, yields:

\[
\begin{align*}
W_{t0} & \quad 105,000 \text{ (lbs)} \\
W_F &= 0.234 W_{t0} \quad 24,570 \text{ (lbs)} \\
W_{t\text{ent}} &= W_{t0} - W_F - 20,500 \quad 59,930 \text{ (lbs)} \\
W_{t\text{ent}} &= W_{t\text{ent}} - 0.005 W_{t0} - 820 \quad 58,585 \text{ (lbs)}
\end{align*}
\]

The error between the predicted empty weight and the allowable empty weight is:

\[
\% \text{ error} = \frac{58,608 - 58,585}{58,608} \times 100\% = 0.04\%
\]
TABLE L.1 PRELIMINARY WEIGHTS AND WEIGHT SENSITIVITIES FOR THE 100 PASSENGER COMMUTER

WEIGHTS:
- Take-Off Weight, \( W_{TO} = 112,288 \) lbs
- Operating Weight Empty, \( W_{OEW} = 67,422 \) lbs
- Empty Weight, \( W_E = 66,041 \) lbs
- Payload Weight, \( W_{PL} = 20,500 \) lbs
- Mission Fuel Weight, \( W_F = 24,366 \) lbs

WEIGHT SENSITIVITIES:
- Payload Weight: \( \frac{dW_{TO}}{dW_{PL}} = 5.9 \)
- Empty Weight: \( \frac{dW_{TO}}{dW_E} = 1.6 \)
- Specific Fuel Consumption: \( \frac{dW_{TO}}{dCp} = 202,659 \) lb/lb/lb/hr
- Propeller Efficiency: \( \frac{dW_{TO}}{d\eta_p} = -95,369 \) lbs
- Lift-to-Drag Ratio: \( \frac{dW_{TO}}{d(L/D)} = -5,067 \) lbs
- Range: \( \frac{dW}{dR} = 54.0 \) lb/nm

Wing Area: \( S = 1,604 \) ft
Wing Aspect Ratio: \( AR = 12 \)
Take-Off Power: \( P_{TO} = 26,750 \) hp
Required Lift Coefficients:
- Clean, \( C_{L_{MAX}} = 1.32 \)
- Take-Off, \( C_{L_{MAX,TO}} = 1.80 \)
- Landing, \( C_{L_{MAX,L}} = 3.0 \)
L.3 PRELIMINARY PERFORMANCE SIZING

This section presents the calculations used in the preliminary performance sizing. The methods used are those presented in Reference (1).
1. PRELIMINARY WEIGHT SIZING

THE PRELIMINARY WEIGHT SIZING OF THE NASA-100 WAS DONE WITH THE CALCAE 3 PROGRAM ON THE HARRIS-300 COMPUTER.

ASSUMPTIONS: \( \frac{W_{\text{ALL}}}{W_{\text{ALUM}}} = 0.95 \)

\( W_p = 20,500 \) lbs

\( W_{\text{CREW}} = 820 \) lbs

USING THIS PROGRAM, THE CALCULATED WEIGHTS ARE:

\( W_0 = 112,288 \) lbs

\( W_E = 66,321 \) lbs

\( W_F = 24,363 \) lbs

2. TAKE-OFF WEIGHT SENSITIVITIES

THESE SENSITIVITIES WERE ALSO CALCULATED WITH THE CALCAE 3 PROGRAM.

ASSUMPTIONS: \( C_p = 0.10 \) lb/lb/hr

\( \eta_p = 0.85 \)

\( L/D = 16.0 \)

\( R = 1500 \) nm

GROWTH FACTORS WERE CALCULATED AS:

DUE TO PAYLOAD WEIGHT: \( \frac{\partial W_0}{\partial W_p} = 5.9 \)

DUE TO EMPTY WEIGHT: \( \frac{\partial W_0}{\partial W_E} = 1.6 \)

SENSITIVITIES WERE DERIVED AS:

\( \frac{\partial W_0}{\partial C_p} = 202,659 \) lb/lb/hr

\( \frac{\partial W_0}{\partial \eta_p} = -95,369 \) lbs

\( \frac{\partial W_0}{\partial (L/D)} = -5,067 \) lbs

\( \frac{\partial W_0}{\partial R} = 54.0 \) lb/nm
3. PRELIMINARY PERFORMANCE SIZING

THE PRELIMINARY PERFORMANCE SIZING OF THE NASA-100 WAS DONE WITH THE CADAE 2 PROGRAM ON THE HARRIS-800 COMPUTER.

TAKE-OFF DISTANCE, LANDING DISTANCE, AND CRUISE SPEED PROVED TO BE THE CRITICAL PERFORMANCE CRITERIA. SEE FIG. 1.

ASSUME: A = 12

3.1 STALL SPEED REQUIREMENTS

AT \( V_s (FLAPS-UP) = 120 \text{ kts} \), \( (w/s)_T0 = 73.2 \text{ psf} \)

AT \( V_s (FLAPS-DOWN) = 100 \text{ kts} \), \( (w/s)_T0 = 88.1 \text{ psf} \)

3.2 DRAG POLARS

LOW SPEED, GEAR DOWN: \( C_D = 0.0629 + 0.0312 C_L^2 \)

TAKE-OFF, GEAR UP: \( C_D = 0.0779 + 0.0332 C_L^2 \)

TAKE-OFF, GEAR DOWN: \( C_D = 0.0979 + 0.0332 C_L^2 \)

LANDING, GEAR UP: \( C_D = 0.0929 + 0.0332 C_L^2 \)

LANDING, GEAR DOWN: \( C_D = 0.1129 + 0.0332 C_L^2 \)

3.3 TAKE-OFF DISTANCE

THE VALUES OF POWER LOADING CORRESPONDING TO VARIOUS WING LOADINGS AND MAXIMUM TAKE-OFF LIFT COEFFICIENTS IS FOUND IN TABLE 1.

3.4 LANDING DISTANCE

THE RELATION BETWEEN WING LOADING AND \( C_L \text{max} \) IS GIVEN AS:

\( (w/s)_T0 = 23.40 \times C_L \text{max} \)

THE VALUES SATISFYING THIS RELATION ARE PRESENTED IN TABLE 2.

3.5 CLIMB REQUIREMENTS

ALL CLIMB REQUIREMENT VALUES OF POWER LOADING ARE PRESENTED IN TABLE 3.
### Table 1 -- Power Loadings to Meet Take-Off Distance Requirements

<table>
<thead>
<tr>
<th>$(W/S)_{to}$ psf</th>
<th>$C_{L_{max}}$</th>
<th>1.00</th>
<th>1.50</th>
<th>2.00</th>
<th>2.50</th>
<th>3.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.0</td>
<td>13.5</td>
<td>20.2</td>
<td>26.9</td>
<td>33.7</td>
<td>40.4</td>
<td></td>
</tr>
<tr>
<td>40.0</td>
<td>6.7</td>
<td>10.1</td>
<td>13.5</td>
<td>16.8</td>
<td>20.2</td>
<td></td>
</tr>
<tr>
<td>60.0</td>
<td>4.5</td>
<td>6.7</td>
<td>9.0</td>
<td>11.2</td>
<td>13.5</td>
<td></td>
</tr>
<tr>
<td>80.0</td>
<td>3.4</td>
<td>5.0</td>
<td>6.7</td>
<td>8.4</td>
<td>10.1</td>
<td></td>
</tr>
<tr>
<td>100.0</td>
<td>2.7</td>
<td>4.0</td>
<td>5.4</td>
<td>6.7</td>
<td>8.1</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2 -- Maximum Take-Off Wing Loadings to Meet Landing Distance Requirements

<table>
<thead>
<tr>
<th>$C_{L_{max}}$</th>
<th>$(W/S)_{to , max}$ psf</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>23.10</td>
</tr>
<tr>
<td>1.50</td>
<td>35.11</td>
</tr>
<tr>
<td>2.00</td>
<td>46.81</td>
</tr>
<tr>
<td>2.50</td>
<td>58.51</td>
</tr>
<tr>
<td>3.00</td>
<td>70.21</td>
</tr>
</tbody>
</table>

### Table 3 -- Climb Requirement Power Loadings at $\alpha = 12$°

<table>
<thead>
<tr>
<th>$(W/S)_{to}$ psf</th>
<th>$(W/P)$ lbs/ft²</th>
<th>$(W/P)$ lbs/ft²</th>
<th>$(W/P)$ lbs/ft²</th>
<th>$(W/P)$ lbs/ft²</th>
<th>$(W/P)$ lbs/ft²</th>
<th>$(W/P)$ lbs/ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.0</td>
<td>43.07</td>
<td>41.73</td>
<td>39.00</td>
<td>40.01</td>
<td>28.59</td>
<td>27.58</td>
</tr>
<tr>
<td>40.0</td>
<td>30.45</td>
<td>29.51</td>
<td>27.58</td>
<td>28.29</td>
<td>20.22</td>
<td>19.50</td>
</tr>
<tr>
<td>60.0</td>
<td>24.86</td>
<td>24.09</td>
<td>22.52</td>
<td>23.10</td>
<td>16.51</td>
<td>15.92</td>
</tr>
<tr>
<td>80.0</td>
<td>21.53</td>
<td>20.86</td>
<td>19.50</td>
<td>20.50</td>
<td>14.29</td>
<td>13.79</td>
</tr>
<tr>
<td>100.0</td>
<td>19.26</td>
<td>18.66</td>
<td>17.34</td>
<td>17.89</td>
<td>12.79</td>
<td>12.33</td>
</tr>
</tbody>
</table>

- FAR 25.111
- Initial Climb
- Transition
- Second Segement
- En-Route
- Landing
- Climb
- Balked
- Landing
- Climb
- Segement
- (OEI)
- (OEI)
- (OEI)
- (OEI)
- (OEI)
3.6 MANEUVERING REQUIREMENTS

The calculated relation is as follows:

\[(W/P) = (W/S) / 0.05 + 4640.88 (W/S)\]

The values satisfying this relation are given in Table 4.

3.7 CRUISE SPEED REQUIREMENTS

The calculated relation is:

\[(W/P) = (W/S) / 8.15\]

The values satisfying this relation are given in Table 4.

3.8 MATCHING SIZING REQUIREMENTS

Point \( P_3 \), Fig. 1, was chosen as the point of maximum allowable wing loading:

\[(W/S)_{TO, MAX} = 70 \text{ psf}\]

At this wing loading, the power loading is:

\[(W/P)_{TO} = 4.2 \text{ lbs/} \text{hp}\]

The power required is calculated as:

\[P_{REQD} = 26,736 \text{ hp}\]

The wing area required is:

\[S = 1604 \text{ ft}^2\]

The different requirements of the performance sizing are presented graphically in Fig. 1.


<table>
<thead>
<tr>
<th>(W/S)$_{psf}$</th>
<th>(W/P)$_{to max}$ (static)</th>
<th>(W/P)$_{to max}$ (static)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.0</td>
<td>87.30</td>
<td>1.23</td>
</tr>
<tr>
<td>40.0</td>
<td>41.20</td>
<td>2.45</td>
</tr>
<tr>
<td>60.0</td>
<td>30.08</td>
<td>3.68</td>
</tr>
<tr>
<td>80.0</td>
<td>23.21</td>
<td>4.91</td>
</tr>
<tr>
<td>100.0</td>
<td>19.23</td>
<td>6.14</td>
</tr>
</tbody>
</table>

**TABLE 4 -- Power Loadings Required for Maneuvering and for Cruise Speed**

*MANEUVERING REQUIREMENT*  
*CRUISE SPEED REQUIREMENT*
FIG. 1 - MATCHING RESULTS FOR 100 PASSENGER REGIONAL TURBO-PROP PERFORMANCE SIZING.

\[(\frac{W}{T})_{P_1} = 3.6\]
\[(\frac{W}{T})_{P_2} = 4.0\]
\[(\frac{W}{T})_{P_3} = 4.2\]
L.4 FLAP SIZING

Using methods presented in Reference (2) the flap geometry required to provide the necessary incremental lift coefficients for take-off and landing were calculated. The results are presented in Table L.2.

ORIGINAL PAGE IS OF POOR QUALITY
7.1:
\[ C_{L_{\text{MAX}}} = 1.5 \]
\[ C_{L_{\text{MAX},0}} = 1.8 \]
\[ C_{L_{\text{MAX},L}} = 3.0 \]

7.2: 'LONG-COUPLED' \[ \Rightarrow l_h/\delta > 5.0 \]

**NEEDED:**
\[ C_{L_{\text{MAX},w}} = 1.05 C_{L_{\text{MAX}}} \]
\[ = 1.05 (1.5) \]
\[ C_{L_{\text{MAX},w}} = 1.57 \]

\[ \cos \lambda \theta = 0.9744 \]

\[ C_{L_{\text{MAX},w}} = C_{L_{\text{MAX},w}} ^{\text{UNSWEEP}} / 0.9744 \]
\[ C_{L_{\text{MAX},w}} ^{\text{UNSWEEP}} = 1.61 \]

**ALLOWED:**
\[ \kappa_x = 0.95 \]
\[ x = 0.4 \]

\[ C_{L_{\text{MAX},w}} = \kappa_x (C_{L_{\text{MAX},r}} + C_{L_{\text{MAX},L}})/2 \]
\[ C_{L_{\text{MAX},w}} = 1.42 \]

DONT WORK

**NEEDED:**
\[ C_{L_{\text{MAX},w}} ^{\text{UNSWEEP}} = 1.42 \]
\[ C_{L_{\text{MAX},w}} ^{\text{SWEEP}} = 1.38 \]
\[ C_{L_{\text{MAX}}} = 1.32 \]

**NOW ASSUME**
\[ C_{L_{\text{MAX}}} = 1.32 \]
7.3: \[ \Delta C_{L \text{MAX}} \text{ NEEDED:} \]
\[ \Delta C_{L \text{MAX}_{\text{TO}}} = 1.05 (1.3 - 1.8) \]
\[ \Delta C_{L \text{MAX}_{\text{TO}}} = 0.504 \]

**LANDING:**
\[ \Delta C_{L \text{MAX}_{L}} = 1.05 (3.0 - 1.3) \]
\[ \Delta C_{L \text{MAX}_{L}} = 1.76 \]

7.4: \[ k_a = 0.906 = (1 - 0.08 \cos^2 \Delta \alpha_a) / \cos^3 \Delta \alpha_a \]

<table>
<thead>
<tr>
<th>SWF/S</th>
<th>( SWF )</th>
<th>( \Delta C_{L \text{MAX}_{\text{TO}}} )</th>
<th>( \Delta C_{L \text{MAX}_{L}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>5.00</td>
<td>2.28</td>
<td>7.95</td>
</tr>
<tr>
<td>0.3</td>
<td>3.33</td>
<td>1.52</td>
<td>5.29</td>
</tr>
<tr>
<td>0.4</td>
<td>2.50</td>
<td>1.14</td>
<td>3.97</td>
</tr>
<tr>
<td>0.5</td>
<td>2.00</td>
<td>0.914</td>
<td>3.18</td>
</tr>
<tr>
<td>0.6</td>
<td>1.67</td>
<td>0.763</td>
<td>2.65</td>
</tr>
<tr>
<td>0.7</td>
<td>1.43</td>
<td>0.653</td>
<td>2.27</td>
</tr>
<tr>
<td>0.8</td>
<td>1.25</td>
<td>0.571</td>
<td>1.99</td>
</tr>
<tr>
<td>0.9</td>
<td>1.11</td>
<td>0.507</td>
<td>1.76</td>
</tr>
</tbody>
</table>

7.5: \[ C_{L \alpha} = \frac{\alpha}{\pi} \text{; FOWLER FLAPS;} \]
\[ S_{\alpha_{\text{TO}}} = 20 \text{.leg;} \quad S_{\alpha_{\text{L}}} = 40 \text{.leg;} \quad \Delta C_{f} = C_{L \alpha} \cdot \alpha_{\text{f}} \cdot S_{f} \]

**OBTAINABLE VALUES:**

<table>
<thead>
<tr>
<th>( C_{L \alpha} / C )</th>
<th>( K )</th>
<th>( \alpha_{\text{f}_{\text{TO}}} )</th>
<th>( \alpha_{\text{f}_{\text{L}}} )</th>
<th>( \Delta C_{L_{\text{TO}}} )</th>
<th>( \Delta C_{L_{\text{L}}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>0.97</td>
<td>7.85</td>
<td>0.49</td>
<td>0.40</td>
<td>1.33</td>
</tr>
<tr>
<td>0.30</td>
<td>0.94</td>
<td>3.17</td>
<td>0.54</td>
<td>0.42</td>
<td>1.54</td>
</tr>
<tr>
<td>0.35</td>
<td>0.83</td>
<td>3.43</td>
<td>0.56</td>
<td>0.46</td>
<td>1.06</td>
</tr>
</tbody>
</table>

(Fig. 7A) (Eqn. 7.17) (Fig. 7B) (Eqn. 7.3) (Eqn. 7.4)
### Results: CH. 7

- \( C_{L_{max}} = 1.32 \)

\[
\begin{align*}
C_{L_{max, T0}} &= 1.80 \\
C_{L_{max, L}} &= 3.00 \\
S_{SWF}/S &= 0.7 \\
S/S_{SWF} &= 1.43 \\
\Delta C_{L_{T0}} &= 0.695 \quad \text{ALLOWED: } \Delta C_{L_{T0}} = 1.54 \\
\Delta C_{L_{L}} &= 2.41 \quad \text{ALLOWED: } \Delta C_{L_{L}} = 2.40
\end{align*}
\]

- \( c/c = 0.30 \)

- \( S_{F_{T0}} = 20 \text{ deg} \)

- \( S_{F_{L}} = 40 \text{ deg} \)

- **Fowler Flaps**

- \( C_{10f} = 2\pi \)

- \( \Delta C_{L_{max, T0}} = 0.453 \quad \text{NEEDED: } 0.504 \)

- \( \Delta C_{L_{max, L}} = 2.27 \quad \text{NEEDED: } 1.76 \)
6.8: AILERON CHORD RATIO: 0.30
AILERON SPAN RATIO: 0.76 - 1.00 \( \text{SEE CH. 7} \)
(FUSELAGE: 0.0 to 0.76 span)

6.9: REAR SPAR LOCATION:
\[(1 - 0.30 - 0.005)c = 0.695c\]
(CLEARANCE)
FRONT SPAR: ASSUME: 0.20c

6.10: WING FUEL VOLUME:
ASSUME: No fuel beyond 0.85 span
ASSUME: Dry bays needed.

\[
\tau_w = \frac{(\frac{c}{L})_c}{(\frac{c}{L})_r} = \frac{0.13}{0.13} = 1.0
\]
\[
\lambda_w = 0.4 \text{ (GIVEN)}
\]
\[
(\frac{c}{L})_r = 0.13
\]

\[
S = 1604 \text{ ft}^2
\]
\[
b = 138.7 \text{ ft}
\]
\[
0.85b = 118 \text{ ft}
\]

\[
V_{WF} = 0.54 \left(\frac{1604}{138.7}\right)^2 (0.13) \cdot \frac{\xi(1+0.4+0.16)(1+0.4)^2}{(1+0.4)^2}^2
\]

\[
V_{WF} = 1036 \text{ ft}^2
\]

NEEDED: \[V_{WF} = \frac{W_F}{49.0 \text{ lbs/ft}^3} \text{ (JP-4)} \]

\[= 24,363 \text{ lbs} \times 49.0\]

\[
V_{WF} = 497 \text{ ft}^3
\]
### TABLE L.2 100 PASSENGER FLAP GEOMETRY

**Trailing Edge Fowler Flaps**

- $C_f/c = 0.30$
- $S_{wf}/S = 0.70$
- $b_f/b = 0.76$
- $\delta_{f_{TO}} = 20 \text{ deg}$
- $\delta_{f_{L}} = 40 \text{ deg}$
L.5 CLASS I EMPENNAGE SIZING

This section presents the sizing of a conventional T-tail empennage using the $\overline{V}$-bar method presented in Reference (2).
2.1 CONFIGURATION: T-TAIL

WITH ENGINE IN THE MIDDLE OF THE VERTICAL TAIL.

NEED $15^\circ$ CLEARANCE FOR TAKE-OFF

3 - ENGINE CONFIG: TURBO-PROP

2.2 DISPOSITION OF THE EMPENNAGE

ASSUME: $X_V = 49.0$ ft

$X_h = 58.0$ ft

2.3 DETERMINATION OF THE EMPENNAGE SIZE

GIVEN: $\bar{V}_h = 108$

$Se/s_h = 0.36$

$\bar{V}_V = 0.083$

$Sr/s_v = 0.34$

$Se/s = 0.06$

$S_h = \frac{\bar{V}_h}{X_h}$ $Se/2$  

$S_v = \frac{\bar{V}_V}{X_v}$ $Sb/2$  

ORIGINAL PAGE IS OF POOR QUALITY.
FROM PRELIMINARY SIZING: (PAGE 3)

\( b = 139 \text{ ft} \)
\( e = 11.6 \text{ ft} \)
\( s = 1604 \text{ ft}^2 \)

THUS:

\[ S_h = \frac{1.08 \times (1604 \times 11.6)}{58} \]
\[ S_h = 347 \text{ ft}^2 \]

\[ S_v = \frac{0.083 \times (1604 \times 139)}{99} \]
\[ S_v = 378 \text{ ft}^2 \]

8.5 DETERMINATION OF RUDDER AREA:

\[ (S_r/S_v)(S_v) \]

\[ S_r = (0.34)(378) = 129 \text{ ft}^2 \]

ELEVATOR AREA:

\[ S_o = (0.36)(347) = 125 \text{ ft}^2 \]
L.6 CLASS I LANDING GEAR DESIGN

From chapter 9 in Reference (2) it was decided to choose a 30 inch diameter tire 9 inches wide. This tire can carry a 20,000 pound load.

From weight and balance calculations longitudinal gear placement criterion were met. There is 15 degrees between the main gear ground contact point and the forward c.g.

Figure L.1 shows that the lateral tip-over criterion is met for a 228 inch wheel base.
3.1 CHAP 9:

9.1: CHOICE: RETRACTABLE LANDING GEAR

9.2: CHOICE: TRICYCLE CONFIGURATION

9.3: GO TO CHAP. 10.

CHAP 10: CLASS I WEIGHT AND BALANCE

10.1: CLASS I COMPONENT WEIGHT BREAKDOWN

<table>
<thead>
<tr>
<th>Component</th>
<th>W (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuselage Group</td>
<td>14,260</td>
</tr>
<tr>
<td>Wing Group</td>
<td>13,043</td>
</tr>
<tr>
<td>Empennage Group</td>
<td>3,256</td>
</tr>
<tr>
<td>Engine Group</td>
<td>14,260</td>
</tr>
<tr>
<td>Landing Gear Group</td>
<td>4,828</td>
</tr>
<tr>
<td>Fixed Equipment Group</td>
<td>16,394</td>
</tr>
<tr>
<td>Trapped Fuel &amp; Oil</td>
<td>561</td>
</tr>
<tr>
<td>Crew</td>
<td>820</td>
</tr>
<tr>
<td>Fuel</td>
<td>24,346</td>
</tr>
<tr>
<td>Passengers</td>
<td>17,500</td>
</tr>
<tr>
<td>Baggage</td>
<td>3,000</td>
</tr>
<tr>
<td>Cargo</td>
<td>0</td>
</tr>
<tr>
<td>Military Load</td>
<td>0</td>
</tr>
</tbody>
</table>

\[ W_{TO} = 12,233 \text{ lbs} \]

\[ W_{E} = \sum_{i=1}^{13} W_i = 14,260 \]
\[ \begin{align*}
13,043 \\
3,256 \\
14,260 \\
4,828 \\
16,394 \\
66,041 \\
\end{align*} \]

\[ W_{OE} = \sum_{i=1}^{13} W_i = 65,041 \]
\[ \begin{align*}
561 \\
820 \\
24,346 \\
17,500 \\
3,000 \\
0 \\
67,422 \\
\end{align*} \]

10.2: SEE DRAWING 1.

ORIGINAL PAGE IS OF POOR QUALITY.
7.5: MAXIMUM STATIC LOAD PER STRUT:

\[ P_n = \frac{(W_0 \cdot l_m)}{(l_m + l_n)} \quad \text{(NOSE - WHEEL STRUT)} \]

\[ P_m = \frac{(W_0 \cdot l_n)}{n_3 \cdot (l_m + l_n)} \quad \text{(MAIN-GEAR STRUT)} \]

\[ C_g \cdot W_0 = 957 \text{ F.S.} \]

\[ l_m = (1005 - 957) \text{ in} = 48 \text{ in} \quad \text{SCALE FROM DRAWING} \]

\[ l_n = (957 - 246) \text{ in} = 711 \text{ in} \]

\[ l_m + l_n = 711 + 48 = 759 \text{ in} \]

NOSE - WHEEL:

\[ P_n = \frac{(112,238 \text{ lbs})(48 \text{ in})}{(759 \text{ in})} \]

\[ P_n = 7101 \text{ lbs} \]

MAIN-GEAR:

\[ P_m \cdot n_3 = \frac{(112,238 \text{ lbs})(711 \text{ in})}{(759 \text{ in})} \]

\[ P_m \cdot n_3 = 105,187 \text{ lbs} \]

\[ \frac{P_m}{2 \cdot \text{struts}} = \frac{105,187}{2} = 52,594 \text{ lbs/strut} \]

9.6: WHEELS PER STRUT: 2 (NOSE), 4 (MAIN)

9.7: COMPUTE:

\[ \frac{P_n}{W_0} = \frac{7101 \text{ lbs}}{112,238 \text{ lbs}} = 0.063 \]

\[ \frac{n_3 P_m}{W_0} = \frac{105,187}{112,238} = 0.937 \]

CORRELATES TO VALUES IN TABLE 9.2.

TIRES: 30'' x 9'' (10 TIRES)
FIG. L.1 -- TEST FOR LATERAL TIP-OVER CRITERIA

Zcg = 148 in. above ground line
L = 104 in.

Hg: FS. 1005
Most Fwd CG: FS. 957

I = 104 in.

14 in.

Hg: FS. 246
Ng: FS. 246

Morgan / Robinson
Landing Gear
100-Pax

10-21
L.7 STABILITY AND CONTROL CALCULATIONS

Calculation of required stability derivatives are presented in this section.

- Calculation of $C_{L\alpha w}$
- Calculation of $d\bar{q}/d\alpha$
- Calculation of $dM/d\alpha$
- Calculation of $\bar{\pi}_{aC WB}$
- Calculation of $C_{L\alpha H}$
- Calculation of $\bar{\pi}_{aC A}$
- Calculation of $c_{\eta B}$
- Calculation of $C_{L\alpha L}$
- Calculation of $c_{\eta H}$
- Calculation of $c_{\eta R}$

Engine out calculations

L.34
L.35
L.36
L.37
L.38
L.39
L.40
L.41
L.42
L.43
L.43
### Determination of $C_{L_{max}}$ using Polhamus

Given:
- $A = 12$
- $\lambda = 0.9$
- $\Lambda_{LE} = 15^\circ$
- $M = 0.90$

\[ \beta = \sqrt{1 - M^2} = 0.714 \]

\[ K = \frac{a_0}{2\pi} \frac{1}{\beta} \]

\[ K = 6.01/2\pi/0.714 = 0.683 \]

\[ K = 1 + \varepsilon (0.2 - 2.3 \Lambda_{LE}) - (0.22 - 0.153 \Lambda_{LE}) \frac{A^3}{100} \]

\[ \tan \Lambda_{LE} = \tan \Lambda_{C/2} + (2/A)(1 - 0.1/1.2) \]

\[ - \Lambda_{C/2} = 16^\circ \]

\[ K = 1.054 \]

*Original page is of poor quality*
POLHAMUS GIVES:

\[
\frac{K C_{l_{aw}}}{A} = \frac{2 \pi}{z + \sqrt{\frac{A^2 z^2}{\pi^2} \left(1 + \tan^2 \frac{\pi n^2 - \lambda}{\pi L} \right) + 4}}
\]

\[C_{l_{aw}} = 4.72 \text{ rad}^{-1} = 0.0824 \text{ deg}^{-1}\]

\[
\begin{align*}
\text{Corrected factor for } \frac{dE}{dx}: \\
d\bar{E} \Big|_{0.05} &= \left(0.0924\right) \\
\frac{d\bar{E}}{dx} &= \left(0.09\right) \\
d\bar{E}^{-1} &= \left(1.03\right)
\end{align*}
\]

\[
\begin{array}{|c|c|c|}
\hline
\text{Segment} & \frac{dE}{dx} \mid_{0.05} & \frac{dE}{dx} \mid_{0.0924} \\
\hline
1 & 1.00 & 1.03 \\
2 & 1.00 & 1.03 \\
3 & 1.10 & 1.13 \\
4 & 1.18 & 1.22 \\
5 & 2.00 & 2.06 \\
\hline
\end{array}
\]
\( \frac{d\bar{e}}{d\alpha} \) FOR SEGMENTS 6 - E(2)

\[ l_h = 695 \; ; \; C_f = 200 \]

FROM FIG 3.25 IN THE SS&O BOOK:

\[ \frac{d\bar{e}}{d\alpha} = 0.167 \]

FROM FIG 3.26 IN THE SS&O BOOK, CORRECTION FACTOR = 0.970 \( \Rightarrow \) (1 - \( \frac{d\bar{e}}{d\alpha} \)) = 0.838

<table>
<thead>
<tr>
<th>SEGMENT</th>
<th>( x_i / l_h )</th>
<th>( \frac{d\bar{e}}{d\alpha} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0.136</td>
<td>0.114</td>
</tr>
<tr>
<td>7</td>
<td>0.417</td>
<td>0.349</td>
</tr>
<tr>
<td>8</td>
<td>0.686</td>
<td>0.575</td>
</tr>
<tr>
<td>E(1)</td>
<td>0.324</td>
<td>0.272</td>
</tr>
<tr>
<td>E(2)</td>
<td>0.324</td>
<td>0.272</td>
</tr>
</tbody>
</table>

DETERMINATION OF \( \frac{dM}{d\alpha} \):

\[
\frac{dM}{d\alpha} = \frac{\bar{q}}{36.5} \sum_{i=1}^{nF} \Delta x_i \left( \frac{d\bar{e}}{d\alpha} \right) \]

\[
\frac{dM}{d\alpha} = \frac{\bar{q}}{36.5} \left[ (579) + (207) + (256) + (924) + (1522) + (113) + (324) + (440) + 2(32) \right]
\]

\[
\frac{dM}{d\alpha} = 157\bar{q}
\]

ORIGINAL PAGE IS OF POOR QUALITY
\[ \Delta \bar{X}_{ac, body} = \frac{-\frac{dM}{d\alpha} \ (deg^{-1})}{\bar{g} \cdot S \cdot C_{\alpha, w} \ (deg^{-1})} \]

\[ \Delta \bar{X}_{ac, body} = \frac{-157.2 \ \bar{g}}{\bar{g} (1604 \times 11.5 \times 0.0824)} \]

\[ \Delta \bar{X}_{ac, body} = -0.103 \]

**Assume:** \[ \bar{X}_{ac, w} = 0.25 \]

\[ \bar{X}_{ac, w_3} = 0.15 \]
CLASS I STABILITY AND CONTROL ANALYSIS.

STEP 11.1 LONGITUDINAL X- PLOT

\[
\overline{X_{ac}}_A = \left[ \frac{X_{ac,\omega} + \left[ C_{\lambda h} \left( 1 - d \varepsilon_h / d\alpha \right) (S_h / S) X_{ac,\omega} \right]}{C_{\lambda h, \omega}} \right] \]

WHERE \( F = \left[ 1 + \varepsilon C_{\lambda h} (1 - d \varepsilon_h / d\alpha) (S_h / S)^3 / C_{\lambda h, \omega} \right] \)

DETERMINATION OF \( C_{\lambda h} \):

\( A = 5.3 \); \( \beta = 0.35 \); \( \Lambda_{LE} = 29^\circ \)

\( M = 0.70 \); \( \beta = 0.714 \); \( K = 0.683 \)

\( K = 1 + \varepsilon (2.1 - 2.3 \Lambda_{LE}) -(0.22 - 0.153 \Lambda_{LE}) A \) \( A \) \(^2 \) / 100

\( \tan \Lambda_{LE} = \tan \Lambda_{1/2} + (2/\kappa) (1 - 2/(1 + 2)) \)

\( \Lambda_{1/2} = 20.4^\circ \); \( \kappa = 1.06 \)

\( K C_{\lambda h} = \frac{2 \pi}{A} \sqrt{\frac{A^2 C^2}{K^2} (1 + \frac{\tan^2 \Lambda_{1/2}}{\kappa^2}) + 4} \)

\( C_{\lambda h} = 3.67 \text{ rad}^{-1} = 0.0641 \text{ deg}^{-1} \)

\( 3.82 \text{ rad}^{-1} \) \( \pm \) 22°

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\[
\text{GIVEN} \quad C_{L_{\text{dh}}} = 3.67 \text{ rad}^{-1}, \quad C_{L_{\text{awb}}} = 4.22 \text{ rad}^{-1}
\]

\[
\bar{X}_{uvh} = 5.62, \quad (1 - d \bar{e} / d h) = 0.838
\]

\[
S_h = 349\text{ft}^2, \quad S = 1609\text{ft}^2
\]

\[
F = 1 + 5.056 \times 10^{-4} S_h
\]

\[
\bar{X}_{\text{ac}_A} = \frac{0.150 + 0.00255 S_h}{1 + 4.54 \times 10^{-4} S_h}
\]

<table>
<thead>
<tr>
<th>$S_h$</th>
<th>$\bar{X}_{\text{ac}_A}$</th>
<th>$W_h$ (lbs)</th>
<th>$\bar{X}<em>{c</em>{29\text{act}}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.387</td>
<td>617</td>
<td>0.435</td>
</tr>
<tr>
<td>120</td>
<td>0.432</td>
<td>790</td>
<td>0.442</td>
</tr>
<tr>
<td>130</td>
<td>0.455</td>
<td>802</td>
<td>0.449</td>
</tr>
<tr>
<td>150</td>
<td>0.500</td>
<td>925</td>
<td>0.457</td>
</tr>
<tr>
<td>170</td>
<td>0.542</td>
<td>1049</td>
<td>0.469</td>
</tr>
<tr>
<td>190</td>
<td>0.584</td>
<td>1172</td>
<td>0.471</td>
</tr>
<tr>
<td>210</td>
<td>0.626</td>
<td>1296</td>
<td>0.486</td>
</tr>
</tbody>
</table>

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STATIC MARGIN:

\[
dC_m / dC_L = \overline{X_{cg}} - \overline{X_{ac}} = -0.05 \quad (11.4)
\]

THE LONGITUDINAL X- PLOT GIVES:

\[
\overline{X_{cg,1x}} = 0.456, \quad \overline{X_{ac}} = 0.506
\]

\[
dC_m / dC_L = -0.05 \quad \text{FOR} \quad S_B = 155 \, \text{ft}^2
\]

STATIC DIRECTIONAL STABILITY (DIRECTIONAL X- PLOT)

\[
C_{n \varphi} = C_{n \varphi_w} + C_{n \varphi_B} + C_{n \varphi_V} \left( \frac{S_v}{S} \right) \left( \frac{X_v}{b} \right) \quad (11.8)
\]

ASSUME: \( C_{n \varphi_w} = 0 \)

\[
C_{n \varphi_B} = -57.3 \, \text{KN} \, K_R \frac{S_{B_3}}{S} \frac{l_B}{b} \quad (\text{rad}^{-1}) \quad (7.76)
\]

\[
S_{B_3} = 127.361 \, \text{in}^2 = 884 \, \text{ft}^2
\]

\[
l_B = 1520 \, \text{in} \quad \text{h}_1 = 97 \, \text{in}
\]

\[
X_m = 886 \, \text{in} \quad h_2 = 97 \, \text{in}
\]

\[
h = 97 \, \text{in} \quad \text{h} = 97 \, \text{in}
\]

\[
\frac{X_m}{l_B} = 0.584 \quad \frac{l_B^2}{S_{B_3}} = 18.1
\]

\[
\sqrt{\frac{h_1}{h_2}} = 1 \quad \frac{h}{w} = 1
\]
FROM FIGURE 7.19:

$$K_n = 0.00085$$

$$R_{fuselage} = \frac{V_f}{V}$$

GIVEN: $V = 6 \times 3 \text{ ft/sec}$, $L = 126.7 \text{ ft}$

$V = 3.50 \times 10^{-4} \text{ ft}^2/\text{sec}$

$$R_{fuselage} = 2.52 \times 10^8$$

FROM FIGURE (7.20)

$$K_{L2} = 2.13$$

Thus:

$$C_{n_{FB}} = (-5.73(0.00085)) (2.13) \left( \frac{0.84}{160} \frac{126.7}{152} \right)$$

$$C_{n_{FB}} = -0.0521 \text{ rad}^{-1} = 0.0091 \text{ deg}^{-1}$$

Using Polhamus for $C_{L_{av}}$:

$$A = 1.4, \quad \lambda = 0.6, \quad \Lambda_{L2} = 45^{\circ}, \quad \beta = 10$$

$$X = 0.956$$

$$K = 1 + \varepsilon \left( 0.2 + 2.3 \Lambda_{L2} \right) - \left( 0.22 - 0.153 \Lambda_{L2} \right) A^2 / 100$$

$$\tan \Lambda_{L2} = \tan \Lambda_{c/2} + \left( 2/A \right) (1-2/1+2)$$
\[
\Lambda \gamma = 3.4^\circ \quad \Rightarrow \quad \alpha = 1.061
\]

\[
\frac{\alpha}{\tan^{-1} \left( \frac{\Delta \gamma}{\tan \alpha} \right)} = \frac{2 \gamma}{A}
\]

\[
\Rightarrow \quad C_{Lav} = 1.66 \quad \text{rad}^{-1} = 0.0290 \text{ deg}^{-1}
\]

Thus:

\[
C_{n\gamma} = (-0.0521 \text{ rad}^{-1}) + (0.0290 \text{ deg}^{-1}) \times \frac{S_v}{S} \times \frac{X_v}{b}
\]

Where: \(X_v = 635 \text{ in} \quad b = 139 \text{ ft} = 1668 \text{ in} \)

\[
C_{n\beta} = (-9.093 \times 10^{-4} \text{ deg}^{-1}) + (0.0110 \text{ deg}^{-1}) \times \frac{S_v}{S}
\]

Using \(S_v = 1601 \text{ ft}^2\) yields:

<table>
<thead>
<tr>
<th>(S_v (\text{ft}^2))</th>
<th>(C_{n\beta} \text{ (deg}^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>0.000123</td>
</tr>
<tr>
<td>200</td>
<td>0.000167</td>
</tr>
<tr>
<td>250</td>
<td>0.000211</td>
</tr>
<tr>
<td>270</td>
<td>0.000249</td>
</tr>
<tr>
<td>280</td>
<td>0.000287</td>
</tr>
<tr>
<td>290</td>
<td>0.000315</td>
</tr>
</tbody>
</table>

From the directional x-plot, the required vertical tail area needed for \(C_{n\beta} = 0.00123\) \(\gamma\) is found to be

\[
S_v = 277 \text{ ft}^2
\]
MINIMUM CONTROL LOST WITH ONE ENGINE INOPERATIVE.

STEP 11/12 DETERMINATION OF THE CRITICAL
ENGINE-OUT YAWING MOMENT:

\[ N_{t_{\text{crit}}} = T_{\text{toe}} \gamma_t \]

\[ \gamma_t = 60 \text{ in} \]

\[ T_{\text{toe}} = \frac{550 \rho \omega BHP}{V^{1.1}} \]

WHERE: \( V = 181 \text{ ft/sec} \); \( \rho = 0.85 \); BHP = 13,350

\[ T_{\text{toe}} = 31,365 \text{ lb} \]

THUS: \( N_{t_{\text{crit}}} = (31,365 \times 60 \text{ in/12}) = 156,825 \text{ ft-lb} \)

\[ N_D = 0.25 N_{t_{\text{crit}}} = 39,206 \text{ ft-lb} \]

\[ V_m = 1.2 \quad V_s = 1.2(140 \text{ ft/sec}) = 168 \text{ ft/sec} \]

\[ S_r = (N_D + N_{t_{\text{crit}}})/\bar{F}_{mc} \quad S_D C_{n_{s_r}} \]

DETERMINATION OF \( C_{n_{s_r}} \):

FROM: METHODS FOR ESTIMATING STABILITY AND
CONTROL DERIVATIVES OF CONVENTIONAL
SUBSONIC AIRPLANES.

\[ C_{n_{s_r}} = -C_{y_{s_r}} \left( \frac{\dot{\gamma} \cos \alpha + \dot{\psi} \sin \alpha}{b} \right) \]

ORIGINAL PAGE IS OF POOR QUALITY
WHERE: $\alpha = 0^\circ$, $l = 58.5$ in, $b = 1.668$ in

\[ C_{y_\text{fr}} = C_{\text{Ll}} \left[ \frac{(\alpha_{l})_{\text{Ll}}}{(\alpha_{l})_{C_{l}}} \right] (\alpha_{l})_{C_{l}} K' K_b \frac{S_v}{S} \]

WHERE: $C_{\text{Ll}} = 0.030$ $\text{deg}^{-1}$ \hspace{2cm} $(\alpha_{l})_{C_{l}} = -0.73$

\[ \left[ \frac{(\alpha_{l})_{C_{l}}}{(\alpha_{l})_{C_{l}}} \right] = 1.1 \hspace{2cm} K' = 0.65 \hspace{2cm} K_b = 1.0 \]

$S_v = 190 \text{ ft}^2$ \hspace{2cm} $S = 1604 \text{ ft}^2$

\[ C_{y_{fr}} = -9.89 \times 10^{-6} \text{ } S_v \text{ deg}^{-1} \]

\[ C_{m_{fr}} = 3.97 \times 10^{-6} \text{ } S_v \text{ deg}^{-1} \]

\[ \bar{q} = \frac{1}{2} (0.002272)(168 \text{ ft/sec})^2 = 33.5 \text{ lb/ft}^2 \]

\[ \text{THUS:} \quad 25^\circ = \left( \frac{156,825 + 39,206}{(33.5)(1604)(139)(3.97 \times 10^{-6} \text{ } S_v \text{ deg}^{-1})} \right) \]

\[ S_v = 303 \text{ ft}^2 \]
L.8 CALCULATION OF CLASS I DRAG POLARS

This section computes the airplane wetted area and estimates the skin friction drag. Class I drag polars are compared with the polars computed for the performance sizing. Table L.3 contains the drag polars and table L.4 contains a wetted area breakdown.
12.1. AIRPLANE COMPONENTS CONTRIBUTING TO WETTED AREA:

1. Fuselage
2. Wing
3. Empennage
4. Nacelle

WETTED AREA FOR PLANFORM:

\[ S_{\text{WET,PL}} = 2 \times S_{\text{exp, PL}} \left[ 1 + 0.25(\%c)_r \left( 1 + \frac{1 \times \lambda}{1 + L} \right) \right] \]

\[ S_{\text{exp, PL}} = 1604 \text{ sq ft} - \frac{17,700 \text{ sq in}}{144 \text{ sq in/sq ft}} = 1604 - 12.3 \]

\[ S_{\text{WET,PL}} = 1491 \text{ sq ft}. \]

\[ S_{\text{WET,PL}} = 2 \times (1491) \left[ 1 + 0.25(0.13)(1 + 0.4) \right] / (1 + 0.4) \]

\[ S_{\text{WET,PL}} = 3058 \text{ sq ft} \]

WETTED AREA FOR FUSELAGE:

\[ S_{\text{WET,FUS}} = \pi D_f 1_f \left( 1 - 2/\lambda_f \right)^{3/3} \left( 1 + 1/\lambda_f^2 \right) \]

\[ D_f = 96.6 \text{ in} = 8.05 \text{ ft} \]

\[ 1_f = 1520 \text{ in} = 126.7 \text{ ft} \]

\[ \lambda_f = 1_f / D_f = 1520/96.6 = 15.74 \]

\[ S_{\text{WET,FUS}} = \pi \times (8.05) \times (126.7) \left( 1 - \frac{3/5.74}{1} \right)^{3/3} \left( 1 + \frac{1}{15.74} \right) \]

\[ S_{\text{WET,FUS}} = \pi \times (8.05) \times (126.7) \times (0.913) \times (1.004) \]

\[ S_{\text{WET,FUS}} = 2937 \text{ sq ft} \]
WETTED AREA FOR NACELLES:

GIVEN:

\[ S_{wet,nac.} = 124 \text{ sq ft / Engine Installation} \]

WETTED AREA FOR ENGINE PYLONS

\[ S_{wet,pyl.} = (2)(2) \left[ \left( \frac{67 + 8\lambda}{2} \right)(130) \right] = 40040 \text{ sq in} \]

\[ S_{wet,pyl.} = 278 \text{ sq ft} \]

WETTED AREA FOR EMPENNAGE:

\[ (12.1) \quad S_{wet,n} = 2S_{exp \ pif} \left\{ 1 + 0.25 \left( \frac{\gamma_c}{1 + \lambda} \right) \right\}^2 \]

\[ \gamma = 1.0 \]

\[ \gamma_c = 0.13 \]

\[ \lambda_n = 0.35 \]

\[ S_{exp \ pif} = 155 \text{ sq ft} \]

\[ S_{wet,n} = 2(155) \left\{ 1 + 0.25 \left( 0.13 \right) \left( 1 + 0.35 \right) \right\} \]

\[ S_{wet,n} = 320 \text{ sq ft} \]

\[ (12.1) \quad S_{wet,v} = 2S_{exp \ pif} \left\{ 1 + 0.25 \left( \frac{\gamma_c}{1 + \lambda} \right) \right\}^2 \]

\[ S_{exp \ pif} = \frac{303}{190} \text{ sq ft} \]

\[ (\gamma_c)_{e} = 0.13 \]

\[ \gamma = 1.0 \]

\[ \lambda = 0.6 \]

\[ = 2 \left( \frac{303}{190} \right) \left\{ 1 + 0.25 \left( 0.13 \right) \left( 1 + 0.6 \right) \right\} \]

\[ S_{wet,v} = 392.626 \text{ sq ft} \]

\[ S_{wet,total} = (3053 + 2937 + 248 + 278 + 320 + 392.626) \text{ sq ft} \]

\[ S_{wet,total} = 7228.626 \text{ sq ft} \]
FROM FIG 3.22(b), RANGE IS 6000 ft$^3$ to 7300 ft$^3$.

(PART I)

THE VALUE FOUND FOR S$_{\text{WET}}$ LIES INSIDE THIS RANGE.

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12.2: EQUIVALENT PARASITE AREA:

USE FIG 3.21(b) (PART I), AT S$_{\text{WET}}$ = 7467 ft$^2$,

$$f = \frac{18.5}{17.2} ft^2$$

(assuming: $C_f = 0.0025$)

12.3: FIND $C_{D_0}$

$$C_{D_0} = \frac{f}{S} = \frac{18.5}{(17.2 ft^2)/(1604 ft^2)}$$

$$C_{D_0} = 0.0107 \quad 0.0115$$

$$e = 0.85 \quad (\text{assumed})$$

$$C_{D_0 H=7} = 0.0107 + 0.0004 \quad e = 0.0119$$

12.4: COMPRESSIBILITY DRAG INCREMENT:

FROM FIG. 12.7, PART II:

$$\Delta C_{D_0 \text{COMP}} = 0.0004$$

12.5: FLAP DRAG INCREMENTS: (TAKE-OFF AND LAND)

ASSUMED: $\Delta C_{D_0 L} = 0.075 \quad e = 0.80$

$$\Delta C_{D_0 TO} = 0.015 \quad e = 0.90$$

12.6: LANDING GEAR DRAG INCREMENT:

ASSUMED $\Delta C_{D_0 G} = 0.020$
DRAG POLAR CALCULATIONS:

\[ C_D = C_{D0} + C_L^2 / (\pi Ae) \]

\[ (\%D)_{\text{max}} = 0.5 \left( \pi Ae / C_{D0} \right)^{0.5} \]

\[ \Delta A = 12 \]

\[ C_{D0} \text{ (clean)} = 0.0111 \]

\[ \epsilon = 0.85 \]

DRAG INCREMENTS:

\[ \Delta C_{D0,1} = 0.015 \]

\[ \epsilon = 0.80 \]

\[ \Delta C_{D0,2} = 0.075 \]

\[ \epsilon = 0.80 \]

\[ \Delta C_{D0,3} = 0.020 \]

LOW SPEED, CLEAN:

\[ C_D = 0.0119 + C_L^2 / (\pi 12 \cdot 85) = 0.0119 + 0.0312 C_L^2 \]

\[ (\%D)_{\text{max}} = 0.5 \left( \pi 12 \cdot 85 / 0.0119 \right)^{0.5} = 26.8 \quad 25.9 \]

TAKE-OFF FLAPS, GEAR UP:

\[ C_D = (0.0119 + 0.015) + C_L^2 / \pi 12 (80) \]

\[ C_D = 0.0269 + 0.0332 C_L^2 \]

\[ (\%D)_{\text{max}} = 0.5 \left( \pi 12 \cdot 80 / 0.0269 \right)^{0.5} = 170 \quad 16.7 \]

TAKE-OFF FLAPS, GEAR DOWN:

\[ C_D = 0.0269 + 0.020 + 0.0332 C_L^2 = 0.0469 + 0.0332 C_L^2 \]

\[ (\%D)_{\text{max}} = 0.5 \left( 30 \cdot 16 / 0.0469 \right)^{0.5} = 128 \quad 12.7 \]

LANDING FLAPS, GEAR UP:

\[ C_D = 0.0119 + 0.075 + 0.0332 C_L^2 = 0.0869 + 0.0332 C_L^2 \]

\[ (\%D)_{\text{max}} = 0.5 \left( 30 \cdot 16 / 0.0869 \right)^{0.5} = 9.3 \]

LANDING FLAPS, GEAR DOWN:

\[ C_D = 0.0869 + 0.020 + 0.0332 C_L^2 = 0.1069 + 0.0332 C_L^2 \]

\[ (\%D)_{\text{max}} = 0.5 \left( 30 \cdot 16 / 0.1069 \right)^{0.5} = 8.4 \]
### Table L.3 - Initial Drag Polars for NASA-100

<table>
<thead>
<tr>
<th>Preliminary Sizing Results (Based on S = 500 ft²)</th>
<th>Drag Polar</th>
<th>((\frac{C_D}{\rho V^2})_{MAX})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Long Speed, Clean:</td>
<td>0.0629 + 0.0312(C_L^2)</td>
<td>11.28</td>
</tr>
<tr>
<td>2. Take-Off, Gear Up:</td>
<td>0.0779 + 0.0332(C_L^2)</td>
<td>9.83</td>
</tr>
<tr>
<td>3. Take-Off, Gear Down:</td>
<td>0.0979 + 0.0332(C_L^2)</td>
<td>8.77</td>
</tr>
<tr>
<td>4. Landing, Gear Up:</td>
<td>0.0929 + 0.0332(C_L^2)</td>
<td>9.01</td>
</tr>
<tr>
<td>5. Landing, Gear Down:</td>
<td>0.1129 + 0.0332(C_L^2)</td>
<td>8.17</td>
</tr>
</tbody>
</table>

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### CLASS II Results (S = 1600 ft²)

<table>
<thead>
<tr>
<th>(C_d)</th>
<th>Drag Polar</th>
<th>((\frac{L}{D})_{MAX})</th>
<th>((\frac{L}{D})_{CR})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Low Speed, Clean:</td>
<td>0.0111 + 0.0312(C_L^2)</td>
<td>26.8</td>
<td>21.6</td>
</tr>
<tr>
<td>2. Take-Off, Gear Up:</td>
<td>0.0261 + 0.0332(C_L^2)</td>
<td>17.0</td>
<td></td>
</tr>
<tr>
<td>3. Take-Off, Gear Down:</td>
<td>0.0461 + 0.0332(C_L^2)</td>
<td>12.8</td>
<td></td>
</tr>
<tr>
<td>4. Landing, Gear Up:</td>
<td>0.0861 + 0.0332(C_L^2)</td>
<td>9.3</td>
<td></td>
</tr>
<tr>
<td>5. Landing, Gear Down:</td>
<td>0.1061 + 0.0332(C_L^2)</td>
<td>8.4</td>
<td></td>
</tr>
</tbody>
</table>

Preliminary (Based on 1600 ft²)

<table>
<thead>
<tr>
<th>(C_d)</th>
<th>Drag Polar</th>
<th>((\frac{L}{D})_{MAX})</th>
<th>((\frac{L}{D})_{CR})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>0.0196 + 0.0332(C_L^2)</td>
<td>20.2</td>
<td>13.4</td>
</tr>
<tr>
<td>2.</td>
<td>0.0346 + 0.0332(C_L^2)</td>
<td>14.7</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>0.0546 + 0.0332(C_L^2)</td>
<td>11.7</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>0.0946 + 0.0332(C_L^2)</td>
<td>3.9</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>0.1146 + 0.0332(C_L^2)</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>COMPONENT</td>
<td>WETTED AREA (ft²)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------</td>
<td>------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wing</td>
<td>3058</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal Tail</td>
<td>320</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical Tail</td>
<td>626</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuselage</td>
<td>2937</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine Nacelles</td>
<td>124 x 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine Pylons</td>
<td>278 x 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7467</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX M
ENGINEERING CALCULATIONS FOR THE
75 PASSENGER TWIN-BODY CONFIGURATION
TABLE OF CONTENTS

M.1 INTRODUCTION M-1
M.2 STABILITY AND CONTROL CALCULATIONS M-2
M.3 CLASS I DRAG POLARS M-10
M.1 INTRODUCTION

The purpose of this appendix is to present the engineering calculations for the 75 passenger twin-body configuration. These calculations were used for the class I sizing of the airplane.

The stability and control calculations are contained in section M.2. The longitudinal and lateral-directional control surfaces are sized in this section. Section M.3 documents the class I drag polar calculations.
M.2 STABILITY AND CONTROL CALCULATIONS

CENTER OF GRAVITY LOCATION:

\[ S_w = 2(100) = 200 \text{ ft}^3 \]

\[ W_H = 795.6 \text{ lbs} \]

\[ W_H / S_w = 795.6 / 200 = 3.978 \text{ lb/ft}^3 \]

AFT C.G. LOCATION:

\[ W_i = 45308 \text{ lb} \]

\[ W_i / S_w = 27.557 \times 10^6 \text{ lb/ft}^3 \]

\[ X_{C_A} = 608.2 \text{ in} \]

HORIZONTAL TAIL MOMENT ARM: 1045 in

<table>
<thead>
<tr>
<th>( S_w )</th>
<th>( S_{\text{trim}} )</th>
<th>( X_{C_{A_{\text{oft}}}} )</th>
<th>( \bar{X}<em>{C</em>{A_{\text{oft}}}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>120</td>
<td>605</td>
<td>5.46</td>
</tr>
<tr>
<td>70</td>
<td>140</td>
<td>606</td>
<td>5.54</td>
</tr>
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<td>80</td>
<td>160</td>
<td>607</td>
<td>5.63</td>
</tr>
<tr>
<td>90</td>
<td>180</td>
<td>607</td>
<td>5.72</td>
</tr>
<tr>
<td>100</td>
<td>200</td>
<td>608</td>
<td>5.80</td>
</tr>
<tr>
<td>110</td>
<td>220</td>
<td>609</td>
<td>5.89</td>
</tr>
<tr>
<td>120</td>
<td>240</td>
<td>610</td>
<td>5.97</td>
</tr>
<tr>
<td>130</td>
<td>260</td>
<td>611</td>
<td>6.06</td>
</tr>
</tbody>
</table>

AERODYNAMIC CENTER LOCATION:

FROM PREVIOUS STABILITY CALCULATIONS:

\[ \Delta \bar{T}_{A_{C_B}} = -0.39 \]

\[ \bar{T}_{A_{C_{Wb}}} = -0.14 \]

\[ \bar{T}_{A_{C_{h}}} = 5.77 \]

\[ C_{L_{\text{hn}}} = 3.45 \text{ rad}^{-1} \]

\[ (1 - \frac{d_2}{d_1}) = 0.764 \]
\[ T_{0ch} = 1.17 \]
\[ C_{L,n} = 3.31 \text{ red} \]
\[ (1 - \frac{df}{d\alpha})_b = 1.00 \]

- HORIZONTAL TAILS
- ENGINE MOUNTING BAR

\[ \bar{T}_{0ch} = \frac{[T_{0ch,b} + C_{L,n,b} (1 - \frac{df}{d\alpha})_b T_{0ch,b} + C_{L,n,b} (1 - \frac{df}{d\alpha})_b T_{0ch,b}^2 / C_{L,n,b}]}{[1 + \frac{C_{L,n,b} (1 - \frac{df}{d\alpha})_b (2n/3) + C_{L,n,b} (1 - \frac{df}{d\alpha})_b (2n/3)^2 / C_{L,n,b}]} ] \]

\[ \bar{T}_{0ch} = \frac{-1.14 + \{3.45(1.764)(2n/3)(5.77) + (3.31)(1.0)(.226)(1.17)\} / 4.585}{[1 + \frac{3.45(1.764)(2n/3) + (3.31)(1.0)(.226)}{4.585}]} \]

\[ \bar{T}_{0ch} = \frac{-1.14 + \{15.209(2n/3) + .8752\} / 4.585}{[1 + \{2.6358(2n/3) + .7841\} / 4.585]} \]

<table>
<thead>
<tr>
<th>( S_h )</th>
<th>( S_{h_{\text{total}}} )</th>
<th>( \bar{T}_{0ch} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>120</td>
<td>.436</td>
</tr>
<tr>
<td>70</td>
<td>140</td>
<td>.498</td>
</tr>
<tr>
<td>80</td>
<td>160</td>
<td>.558</td>
</tr>
<tr>
<td>90</td>
<td>180</td>
<td>.618</td>
</tr>
<tr>
<td>100</td>
<td>200</td>
<td>.676</td>
</tr>
<tr>
<td>110</td>
<td>220</td>
<td>.732</td>
</tr>
<tr>
<td>120</td>
<td>240</td>
<td>.787</td>
</tr>
<tr>
<td>130</td>
<td>260</td>
<td>.842</td>
</tr>
</tbody>
</table>
STEP 2: DIRECTIONAL STABILITY

CALCULATE LIFT CURVE SLOPE FOR THE VERTICAL TAIL - \( C_{L\nu} \)

GEOmetrical PARAMETERS:

\[ S = 2 \times 130 = 260 \text{ ft}^2 \]
\[ \lambda = 3^\circ \]

\[ \lambda_{\nu} = 58^\circ \]
\[ \alpha = 1.11 \]
\[ Y_v = 34.67 \text{ ft} \]

USING THE POLHAMUS EQUATION:

\[ \chi = 1.0206 \]
\[ k = 0.682 \]
\[ \beta = 0.51 \]
\[ \lambda_{\nu} = 47^\circ \]

\[ C_{L\nu} = \frac{2\pi (1.11)}{\sqrt{2 + \frac{(0.11)^2 (0.5)}{(0.682)^2} \left( 1 + \frac{(0.47)^2}{(0.5)^2} \right) + 4}} \times 1.0206 \]

\[ C_{L\nu} = 1.40 / \text{rad} = 0.0244 / \text{deg} \rightarrow M = 0.70 \]

CALCULATE \( C_{p_b} \)

USING THE METHOD OF REFERENCE 6, \( C_{p_b} \) FOR THE SINGLE FUSELAGE WAS CALCULATED TO BE:

SINGLE BODY: \( C_{p_b} = -0.138 \)

FOR THE TWIN BODY, IT WILL BE ASSUMED THAT \( C_{p_b} \) IS TWICE THAT OF THE SINGLE BODY:

TWIN BODY: \( C_{p_b} = 2 \times (-0.138) = -0.276 \)
CALCULATE $C_{y_{pv}}$ -

The method used for this calculation follows the procedure in Chapter 7 of Reference 6:

$$C_{y_{pv}} = -2 \left( \frac{C_{y_{pv}(WBI)}}{C_{y_{pv(\text{eff})}}} \right) C_{y_{pv(\text{eff})}} \frac{S_y}{5}$$

Using Figure 7.9 of Ref. 6 -

$$\frac{b'_{w}}{b_{w}} = 1.0$$
$$\frac{A_{\text{eff}}}{A} = 1.5$$
$$A_{\text{eff}} = (1.5)(1.11) = 1.67$$

From Figure 7.6 of Ref. 6 -

$$C_{y_{pv(\text{eff})}} = 2.6$$

From Figure 7.10 of Ref. 6 -

$$\frac{b'_{w}}{b_{w}} = 0.2$$
$$\frac{2y_{c}}{b_{w}} = 0.28$$

$$\frac{C_{y_{pv}(WBI)}}{C_{y_{pv(\text{eff})}}} = 0.75$$

$$C_{y_{pv}} = -2 \left( 0.75 \right) (2.6) \left( \frac{S_y}{5} \right)$$

$$C_{y_{pv}} = -0.0052 \ S_y \ \text{rad}^{-1}$$
\[ C_{Pv} = C_{y_v} \left( \frac{dV}{b} \right) \]

\[ C_{Pv} = 0.0052 \, SV \left( \frac{29.2}{109.5} \right) \]

\[ C_{Pv} = 0.00145 \, SV \]

**CALCULATE** \( C_{Pb} \)

\[ C_{Pb} = C_{Pv} + C_{Pb} \]

\[ C_{Pb} = 0.00145 \, SV - 0.276 \]

<table>
<thead>
<tr>
<th>( SV_{TOTAL} ) (ft(^2))</th>
<th>( C_{Pb} ) (rad/( SV ))</th>
<th>( C_{Pb} ) (deg/( SV ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>180</td>
<td>0.014</td>
<td>-0.00244</td>
</tr>
<tr>
<td>200</td>
<td>0.015</td>
<td>0.00262</td>
</tr>
<tr>
<td>220</td>
<td>0.044</td>
<td>0.00768</td>
</tr>
<tr>
<td>240</td>
<td>0.073</td>
<td>0.0127</td>
</tr>
<tr>
<td>260</td>
<td>0.102</td>
<td>0.0178</td>
</tr>
<tr>
<td>280</td>
<td>0.131</td>
<td>0.0229</td>
</tr>
<tr>
<td>300</td>
<td>0.160</td>
<td>0.0279</td>
</tr>
</tbody>
</table>

**ENGINE OUT REQUIREMENTS**

\( V_T = 3.9 \, \text{ft} \)

\( P_{Toe} = 9000 \, \text{shp} \)

\[ T_{Toe} = \frac{550 \, \text{shp} \, \eta_p}{V} \]

\[ T_{Toe} = \frac{(550)(9000)(0.85)}{104} \]

\[ T_{Toe} = 500 \, \text{shp} \, \eta_p \]
\[ T_{20e} = 22,867 \text{ lbs} \]

\[ N_{\text{let}} = \left( 22,867 \right) \left( 3.9 \right) = 89,181 \text{ ft-lbs} \]

\[ N_d = 0.25 \left[ \frac{N_{\text{let}}}{K} \right] \]

\[ N_d = 0.25 \left[ \frac{89,181}{K} \right] = 22,295 \text{ ft-lbs} \]

**Calculate** \( C_{n_d_R} \):

\[ C_{n_d_R} = C_{n_d} \cdot \frac{(\alpha_f)_{ch}}{(\alpha_f)_{cl}} \cdot \frac{K}{K_b} \cdot \frac{S_V}{S} \]

\[ C_{n_d} = 1.475 \]

\[ (\alpha_f)_{ch} = 0.7 \]

\[ (\alpha_f)_{cl} = 1.14 \]

\[ K_b = 1 \]

\[ K' = 0.65 \]

\[ C_{n_d_R} = (1.475) \left( 1.14 \right) \left( 0.7 \right) \left( 0.65 \right) \left( 1.0 \right) \left( \frac{5}{722} \right) \]

\[ C_{n_d_R} = -0.00106 \]

\[ C_{n_d_R} = - C_{n_d} \cdot \frac{S_V}{D} \]

\[ C_{n_d_R} = \left( 0.00106 \cdot S_V \right) \left( \frac{29.2}{104.5} \right) \]

\[ C_{n_d_R} = 0.000296 S_V \]
CALCULATE $\delta_R$ REQUIRED

$$\delta_R = \left( N_0 + N_{stem} \right) / \bar{L} \geq \delta_{\text{req}}$$

$$\bar{L} = \left( \frac{1}{2} \right) \left( 0.003376 \right) \left( 184 \right)^2 = 40.2 \text{ psf}$$

$$\delta_R = \frac{22,295 + 69,181}{40.2 \times 722 \times 104.5 \times 0.0030 s_v}$$

$$\delta_R = \frac{124}{s_v} \text{ rad}$$

$$\delta_R = \frac{7112}{s_v} \text{ deg}$$

<table>
<thead>
<tr>
<th>$s_v$ TOTAL</th>
<th>$\delta_R$ deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>160</td>
<td>44</td>
</tr>
<tr>
<td>180</td>
<td>40</td>
</tr>
<tr>
<td>200</td>
<td>36</td>
</tr>
<tr>
<td>220</td>
<td>32</td>
</tr>
<tr>
<td>240</td>
<td>30</td>
</tr>
<tr>
<td>260</td>
<td>27</td>
</tr>
<tr>
<td>280</td>
<td>25</td>
</tr>
<tr>
<td>300</td>
<td>24</td>
</tr>
<tr>
<td>320</td>
<td>22</td>
</tr>
<tr>
<td>340</td>
<td>21</td>
</tr>
</tbody>
</table>
Figure 10.2 Lateral - Directional X-Plot for the 75 Passenger Twin-Body
M.3 CLASS II DRAG POLARS -

CALCULATE WETTED AREA -

WING -

\[ S_{\text{wet}} = 2 \, S_{\text{exp}} \left[ 1 + 0.25 \left( \frac{c_t}{c} \right) \left( 1 + \frac{\lambda}{\lambda} \right)^2 \right] \]

\[ c_t = \left( \frac{c_t}{c} \right) / \left( \frac{c_t}{c} \right) \]

\[ \lambda = \frac{c_t}{c} \]

FOR THE OUTBOARD WING SECTIONS -

\[ S_{\text{exp}} = (32.7)(8.33)(1.4) \]

\[ S_{\text{exp}} = 381.5 \, \text{ft}^2 \]

\[ c_t = 0.13 / 1.10 = 0.13 \]

\[ \lambda = 4 \]

\[ S_{\text{wet}} = (2)(381.5) \left[ 1 + 0.25(0.13) \left( 1 + (0.3)(1.4) \right) / (1.4) \right]^2 \]

\[ S_{\text{wet}} = 788 \, \text{ft}^2 \]

FOR THE INBOARD WING SECTION -

\[ S_{\text{exp}} = (23.5)(0.75) = 206 \, \text{ft}^2 \]

\[ c_t = 1.0 \]

\[ \lambda = 1 \]

\[ S_{\text{wet}} = (2)(206) \left[ 1 + 0.25(0.2) \left( 1 + 1 \right) / (1+1) \right]^2 \]

\[ S_{\text{wet}} = 218 \, \text{ft}^2 \]

FOR THE TOTAL WING -

\[ S_{\text{wet}} = 788 + 218 = 1006 \, \text{ft}^2 \]
HORIZONTAL TAIL:

\[ S_{\text{wet}} = 2(102) \left[ 1 + 0.25(1.11) \left( 1 + \frac{1.12(1.2)}{1.5} \right)^{1.3} \right] \]

\[ S_{\text{wet}} = 209.8 \text{ ft}^2 \text{ (per H.T.)} \]

\[ S_{\text{wet}} = 2(209.8) = 419.6 \text{ ft}^2 \]

VERTICAL TAIL:

\[ S_{\text{wet}} = 2(267) = 534 \text{ ft}^2 \]

FUSELAGE:

\[ S_{\text{wet}} = 2(1702) = 3404 \text{ ft}^2 \]

NACELLE:

WETTED AREA WAS CALCULATED TO BE:

\[ S_{\text{wet}} = 2(124) = 248 \text{ ft}^2 \]

PYLONS:

ENGINE - FUSELAGE SECTION:

\[ \lambda = 0.83 \quad \tau = 1 \]

\[ S_{\text{exp}} = (6.25)(8.25)(1.83) = 95.3 \]

\[ S_{\text{wet}} = 2(95.3) \left[ 1 + 0.25(1.12)(1.12)(1.23) / (1.33) \right] \]

\[ S_{\text{wet}} = 196 \text{ ft}^2 \]
CENTER SECTION:

\[ S_{up} = (6.83)(6.25) = 42.7 \]
\[ S_{wet} = 2 \left( \frac{42.7}{2} \right) \left( 1 + \frac{2.5}{12} \right) = 88.0 \text{ ft}^2 \]

TOTAL Pylon AREA:

\[ S_{wet} = 2(196) + 88 \]
\[ S_{wet} = 480 \text{ ft}^2 \]

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>WETTED AREA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing</td>
<td>1006</td>
</tr>
<tr>
<td>Horizontal Tail</td>
<td>420</td>
</tr>
<tr>
<td>Vertical Tail</td>
<td>534</td>
</tr>
<tr>
<td>Fuselage</td>
<td>3404</td>
</tr>
<tr>
<td>Nacelles</td>
<td>248</td>
</tr>
<tr>
<td>Pylons</td>
<td>480</td>
</tr>
<tr>
<td>TOTAL</td>
<td>6092</td>
</tr>
</tbody>
</table>

ASSUME: \( C_f = 0.0025 \)

FROM FIG. 3.21b):

\[ f = 14.5 \]
\[ C_{D_0} = \frac{14.5}{722} = 0.0201 \]
$C_{D_0}$ INCREMENTS -

- COMPRESSIBILITY $\Delta C_{D_0} = 0.0002$
- LANDING GEAR $\Delta C_{D_0} = 0.0150$
- LANDING FLAPS $\Delta C_{D_0} = 0.0750$

TAKE-OFF -

$C_{D_0} = 0.0201 + 0.015 = 0.0351$

$\epsilon = 0.80$
$\alpha = 15.1$

$C_D = 0.0351 + 0.0264 C_l^2$

CRUISE -

$C_{D_0} = 0.0201 + 0.0002 = 0.0203$

$\epsilon = 0.85$
$\alpha = 15.1$

$C_D = 0.0203 + 0.0248 C_l^2$

LANDING -

$C_{D_0} = 0.0201 + 0.0150 + 0.0750 = 0.1101$

$\epsilon = 0.80$
$\alpha = 15.1$

$C_D = 0.1101 + 0.0264 C_l^2$
CRUISE WEIGHT -

\[ W_{CR} = W_0 - 0.9 W_F \]

\[ W_{CR} = 60683 - 0.9(11240) = 56187 \text{ lbs} \]

LIFT COEFFICIENT -

\[ c_{l_{CR}} = \frac{(2)(56187)}{(0.0008897)(696.3)^2} \]

\[ c_{l_{CR}} = 0.36 \]

\[ \frac{L}{D}_{CR} = 0.36/0.0235 \]

\[ \frac{L}{D}_{CR} = 15.3 \]

IF A 10% REDUCTION IN \( C_D \) IS ASSUMED -

\[ \Delta C_D = (0.0203)(0.10) = 0.0020 \]

\[ C_D = 0.0183 + 0.0248 c_l^2 \]

\[ \frac{L}{D}_{CR} = 0.36/0.0215 \]

\[ \frac{L}{D}_{CR} = 16.7 \]
Appendix N:

100 Passenger Twin Body Design Calculations - Class 1 Summary
# Table of Contents

1. Introduction
2. Landing Gear Criterion
3. Class 1 Weight and Balance
4. Class 1 Stability and Control Calculations
5. Class 1 Drag Polar Calculations
6. Class 1 Inertia Calculations

**ORIGINAL PAGE IS OF POOR QUALITY**
The 50 passenger design is the basis for the 100 passenger twin body design. The preliminary weight and performance sizing was used for the twin body design but multiplied by a factor of 2. Also, the class I sizing of the following components was used for the twin body design:

- cockpit and fuselage layouts
- wing planform design
- sizing and location of lateral control surfaces
- sizing high lift devices
- Empennage sizing by V-bar method
- Landing gear sizing and disposition

For detailed calculations of the above, the 50 passenger design will have to be consulted.
N.2 Landing Gear Criterion

The following pages provides the research on the applicability of the 100 passenger twin body wide wheelbase arrangement.

ORIGINAL PAGE IS OF POOR QUALITY.
For the 100 passenger twin fuselage commuter transport or estimated wheelbase of 50' it is scrutiny.

From, Airports Engineering by Schaefer and Wieden, the following guidelines are given on runway and taxiway dimensions. See attached chart. (Pgs N - )

First, the data compiled, the following conclusions were made:

1. The design can operate out of any existing airport.

2. This design will not be able to operate at general aviation airports. General and basic transport general aviation airports have taxiway widths between 40-60 ft.
N3 Class I Weight and Balance

The following pages give the Class I:

- General arrangement drawing
- Weight and balance calculations
- Weight - e.g. excursion diagram
FIGURE 9.5.2. 100 PASSENGER TWIN BODY GENERAL ARRANGEMENT DRAWING.
<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
<th>x</th>
<th>z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuselage</td>
<td>10,704.00</td>
<td>578.00</td>
<td>148.00</td>
</tr>
<tr>
<td>Wing</td>
<td>7,597.00</td>
<td>672.00</td>
<td>127.00</td>
</tr>
<tr>
<td>Empennage</td>
<td>2,230.00</td>
<td>1,204.00</td>
<td>340.00</td>
</tr>
<tr>
<td>Engine</td>
<td>8,470.00</td>
<td>870.00</td>
<td>222.00</td>
</tr>
<tr>
<td>Nose Gear</td>
<td>746.00</td>
<td>220.00</td>
<td>74.00</td>
</tr>
<tr>
<td>Main Gear</td>
<td>2,994.00</td>
<td>720.00</td>
<td>64.00</td>
</tr>
<tr>
<td>Fixed Equipment</td>
<td>12,354.00</td>
<td>578.00</td>
<td>148.00</td>
</tr>
<tr>
<td><strong>Empty Weight</strong></td>
<td>45,103.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Trapped Fuel/Oil</strong></td>
<td>420.00</td>
<td>745.00</td>
<td>178.00</td>
</tr>
<tr>
<td><strong>Crew</strong></td>
<td>615.00</td>
<td>200.00</td>
<td>120.00</td>
</tr>
<tr>
<td><strong>Operating Empty Weight</strong></td>
<td>46,138.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fuel</strong></td>
<td>13,878.00</td>
<td>672.00</td>
<td>127.00</td>
</tr>
<tr>
<td><strong>Passengers</strong></td>
<td>20,500.00</td>
<td>630.00</td>
<td>148.00</td>
</tr>
<tr>
<td><strong>Take-off Weight</strong></td>
<td>80,516.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Ds-c 10-31-86*

*ORIGINAL PAGE IS OF POOR QUALITY*
### Table 2.5.4 Twin Body 100 Passenger Commuter Class I Weight and Balance Calculation

<table>
<thead>
<tr>
<th>No.</th>
<th>Component</th>
<th>Weight</th>
<th>( X_i )</th>
<th>( Z_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fuselage</td>
<td>10704</td>
<td>578</td>
<td>148</td>
</tr>
<tr>
<td>2</td>
<td>Wing</td>
<td>7597</td>
<td>672</td>
<td>127</td>
</tr>
<tr>
<td>3</td>
<td>Empennage</td>
<td>2438</td>
<td>1204</td>
<td>340</td>
</tr>
<tr>
<td>4</td>
<td>Engine</td>
<td>8470</td>
<td>870</td>
<td>222</td>
</tr>
<tr>
<td>5a</td>
<td>Nose Gear</td>
<td>746</td>
<td>220</td>
<td>74</td>
</tr>
<tr>
<td>5b</td>
<td>Main Gear</td>
<td>2994</td>
<td>720</td>
<td>64</td>
</tr>
<tr>
<td>6</td>
<td>Fixed Eqpt.</td>
<td>12354</td>
<td>578</td>
<td>148</td>
</tr>
</tbody>
</table>

Empty Weight: \( W_E = 45303 \)

\[ X_{cg_{We}} = 686 \]
\[ Z_{cg_{We}} = 161 \]

7. Trapped Fuel and Oil

| 7   | Trapped Fuel and Oil | 420   | 745        | 178       |

Operating Weight Empty: \( W_{OE} = 46338 \)

\[ X_{cg_{Woe}} = 680 \]
\[ Z_{cg_{Woe}} = 160 \]

8. Crew

| 8   | Crew            | 615    | 200        | 120       |

9. Fuel

| 9   | Fuel            | 13878  | 672        | 127       |

\[ W_{OE} + W_F = 60216 \]

\[ X_{cg_{Woe+Wf}} = 678 \]

10. Passengers

| 10  | Passengers     | 20500  | 630        | 148       |

Take-off Weight: \( W_{TO} = 80716 \)

\[ W_{TO} - W_F = 66838 \]

\[ X_{cg_{Wto-Wf}} = 665 \]
FIGURE 25.3: 100-PAX TWIN BODY WEIGHT-C.G. EXCURSION DIAGRAM.
N.4 Class 1 Stability and Control Calculations

The following section provides the complete set of calculations for the Class 1 stability and control calculations.
### 100 Pax - Twin Body

<table>
<thead>
<tr>
<th>Section</th>
<th>ΔXi</th>
<th>( \omega_i (\Xi_i) )</th>
<th>Xi</th>
<th>Xi/( c_f )</th>
<th>( c_f = 123 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>97</td>
<td>70</td>
<td>434.5</td>
<td>3.55</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>97</td>
<td>95</td>
<td>339.5</td>
<td>2.76</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>97</td>
<td>97</td>
<td>242.5</td>
<td>1.97</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>97</td>
<td>97</td>
<td>145.5</td>
<td>1.18</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>97</td>
<td>97</td>
<td>48.5</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>182</td>
<td>97</td>
<td>91</td>
<td>0.74</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>182</td>
<td>91</td>
<td>273</td>
<td>2.22</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>182</td>
<td>60</td>
<td>455</td>
<td>3.70</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>100</td>
<td>300</td>
<td>142</td>
<td>1.15</td>
<td></td>
</tr>
</tbody>
</table>

Note: All dimensions in inches.

The wing lift curve slope has previously been determined to be:

\[ CL_{\alpha_w} = 4.97 \text{ rad}^{-1} = 0.0868 \text{ deg}^{-1} \]

Thus, the \( d\bar{\alpha}/da \) correction factor is

\[
\frac{d\bar{\alpha}}{da}_{0.0868} = 1.085 \left| \frac{d\bar{\alpha}}{da}_{0.08} \right|
\]

The downwash is found from Figure 3.33 of the 550 book

<table>
<thead>
<tr>
<th>Section</th>
<th>( \frac{d\bar{\alpha}}{da} )</th>
<th>( \frac{d\bar{\alpha}}{da} ) corrected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00</td>
<td>1.09</td>
</tr>
<tr>
<td>2</td>
<td>1.00</td>
<td>1.09</td>
</tr>
<tr>
<td>3</td>
<td>1.05</td>
<td>1.4</td>
</tr>
<tr>
<td>4</td>
<td>1.10</td>
<td>1.79</td>
</tr>
<tr>
<td>5</td>
<td>2.70</td>
<td>2.93</td>
</tr>
</tbody>
</table>
Thus, the resulting moment is calculated from:

\[ \frac{dM}{dx} = \frac{256x}{x-5} \]

\[ \frac{dM}{dx} = \frac{256x}{x-5} \]

For sections 6, 7, 8, and 9:

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]

\[ A = 500" \]

\[ \frac{1}{\alpha} = 4.57 \]

\[ \frac{1-\alpha}{\alpha} = 0.070 \]
Step 1. Prepare a longitudinal X-plot for the airplane.

(a) The c.g. leg.

The horizontal tail has been assumed to have the following characteristics:

\[ \delta_h = 130 \text{ ft}^2 \text{ each} \]
\[ W_h = 589 \text{ lbs each} \]

Thus, \[ \frac{W_h}{\delta_h} = 4.53 \text{ psf} \]

From the weight and balance analysis, the following tabulation can be made:

<table>
<thead>
<tr>
<th>( S_h )</th>
<th>( W_h )</th>
<th>( x_{eq} )</th>
<th>( x_{eq, AFT} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>680</td>
<td>681</td>
<td>0.59</td>
</tr>
<tr>
<td>200</td>
<td>906</td>
<td>684</td>
<td>0.62</td>
</tr>
<tr>
<td>250</td>
<td>1133</td>
<td>687</td>
<td>0.65</td>
</tr>
<tr>
<td>300</td>
<td>1359</td>
<td>689</td>
<td>0.67</td>
</tr>
</tbody>
</table>

(b) The a.c. leg.

The following quantities must be determined:

\[ \bar{x}_{ac,wa}, C_{L,a,m}, \frac{dC_l}{dx}, \bar{x}_{ac,n}, C_{L,he}, \frac{dC_l}{dx}, \bar{x}_{ac,he} \]

From Multhopp’s integration,

\[ \bar{x}_{ac,wa} = \bar{x}_{ac,w} + \Delta \bar{x}_{ac} \]
\[ \bar{x}_{ac,wa} = 0.25 - 0.39 \]
\[ \bar{x}_{ac,wa} = -0.14 \]

From the 3 view,

\[ \bar{x}_{ac,n} = 6.50 \]
\[ \bar{x}_{ac,he} = 1.71 \]
\( C_{\text{in}} = \left( \frac{A}{K} \right)^{\frac{2}{2}} \left( 2 + \sqrt{\frac{2AEF^2}{K^2}} \right) \)  \( (2) \)

where:

\( K = 1 + \left( \frac{E}{K} - \frac{\tan^2 \theta}{K} \right) \]

\( \sqrt{E} = \beta \) \( (4) \)

\( \beta = \tan \theta \) \( (5) \)

Assuming \( \alpha = 0.70 \) (wet case) and \( \alpha = 2.5^\circ \)

\( \sqrt{E} = 0.51 \)

\( \beta = 0.71 \)

\( K^2 = 1.0642 \)

And it is known:

\( A = 5.0 \)

\( \lambda_{\alpha} = 28^\circ \)

Therefore:

\( C_{\text{in}} = \left( \frac{5.0}{1.0642} \right)^{\frac{2}{2}} \left( 2 + \sqrt{\left( \frac{2AEF^2}{K^2} \right)} \right) \)

\( C_{\text{in}} = 3.45 \) \( \alpha + \alpha_0 = 0.70 \)

\( C_{\text{in}} = 3.49 \) \( \alpha + \alpha_0 = 0 \)

Figures 3.25 and 3.26 of Airplane Flight Dynamics And Automatic Flight Controls, Part I, will be used to estimate \( d\alpha/d\alpha \).

\( m = 250/705 = 0.33 \)

\( r = 610/705 = 0.87 \)

\( \lambda = 0.60 ; A = 5 ; \lambda_{\alpha} = 25^\circ \)

\( d\alpha/d\alpha = 0.164 \)

\( 1 - d\alpha/d\alpha = 0.836 \)
The lift curve slope for the engine planform is found as follows:

\[ \Delta_{he} = 5.56 \]

\[ \beta^2 = 0.51 \]

\[ K^2 = 3.71 \]

\[ \beta_{le} = 1.06^2 \]

\[ \Delta_{le} = 0^\circ \]

\[ C_{L_{\Delta he}} = \left( \frac{5.56}{1.0623} \right) \times \frac{2 \pi}{2 + \sqrt{(5.56)^2 + 4}} \]

\[ C_{L_{\Delta he}} = 4.13 \text{ rad}^{-1} \]

The downwash gradient is calculated as follows: (method proposed in Reference)

\[ \frac{\partial \delta}{\partial \alpha} \bigg|_{\beta \rightarrow 0} = \frac{\partial \Delta}{\partial \alpha} \bigg|_{\beta \rightarrow 0} \quad C_{L_{\Delta w}} \bigg|_{\beta \rightarrow 0} = 0.992 \frac{\partial \delta}{\partial \alpha} \bigg|_{\beta \rightarrow 0} \]

where

\[ C_{L_{\Delta w}} \bigg|_{\beta} = 5.16 \text{ rad}^{-1} \]

\[ C_{L_{\Delta w}} \bigg|_{\beta = 0} = 5.20 \text{ rad}^{-1} \]

and

\[ \frac{\partial \delta}{\partial \alpha} \bigg|_{\beta = 0} = 4.44 \left( K_A K_\lambda K_H \sqrt{\cos \Delta_{\Delta w}} \right)^{1.19} \]

\[ K_A = \frac{1}{A} - \frac{1}{1 + A^{1.7}} \]

\[ K_\lambda = \frac{10 - 3 \lambda}{7} \]

\[ K_H = \frac{1 - \frac{h_w}{b}}{\sqrt{\frac{2 \gamma f}{h}}} \]

where

\[ A_v = 15 \quad \lambda_w = 0.40 \]

\[ l_{he} = 171^\circ \quad h_{he} = 90^\circ \quad b_w = 118' \]

ORIGINAL PAGE IS OF POOR QUALITY
\[ K_{Mc} = 0.056 \]
\[ K_{Ma} = 1.257 \]
\[ K_{Mc} = 1.504 \]

\[ \frac{dE}{d\alpha} = 0.304 \quad \text{and} \quad \frac{dE}{d\alpha} = 0.304 \]

\[ \text{or} \]

\[ (1 - \frac{dE}{d\alpha}) = 0.697 \]

The a.c. leg is calculated by \( \text{(Eqn. 11)} \)

\[ \bar{X}_{ocA} = \frac{\bar{X}_{ocu} + \left\{ C_{ocMa} \left( 1 - \frac{dE}{d\alpha} \right) (S_{ocu} \bar{X}_{och}) / C_{L_{ocVI}} \right\}}{1 + \left\{ C_{ocMa} \left( 1 - \frac{dE}{d\alpha} \right) (S_{ocu} \bar{X}_{och}) / C_{L_{ocVI}} \right\}} + \left\{ C_{ocNe} \left( \frac{S_{rc}}{S_{ocu}} \bar{X}_{ocNe} \right) / C_{L_{ocVI}} \right\} \]

In the stability and control analysis for the 50 passenger single body, it was found that

\[ S_{h} = 102 \, \text{ft}^2 \]

thus, it will be assumed for commonality that the horizontal tails on the 100-passenger twin body are the same as that on the 50 passenger. Thus,

\[ S_{h} = 204 \, \text{ft}^2 \]

Thus, the above equation reduces to

\[ \bar{X}_{ocA} = \left[ -0.14 + 0.803 + 0.954 \left( \frac{S_{hc}/S}{S_{he}/S} \right) \right] / 1 + 0.1235 + 0.555 \left( \frac{S_{hc}/S}{S_{he}/S} \right) \]

\[ M = 0.70 \]

Table 2. Aerodynamic Center Location For Various Engine Plantform Support Areas.

<table>
<thead>
<tr>
<th>( S_{he}/\text{ft}^2 )</th>
<th>( S_{he}/S )</th>
<th>( \bar{X}_{ocA} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0.590</td>
</tr>
<tr>
<td>100</td>
<td>0.108</td>
<td>0.647</td>
</tr>
<tr>
<td>200</td>
<td>0.217</td>
<td>0.699</td>
</tr>
<tr>
<td>300</td>
<td>0.325</td>
<td>0.746</td>
</tr>
</tbody>
</table>
By assuming the horizontal tail weight is fixed at

\[ W_h = 92.4 \text{ lbs} \quad \Rightarrow \quad x_{c_h} = 0.620 \]

Then for the airplane to be inherently stable with a 5 percent static margin,

\[ x_{ace} = 0.670 \]

and

\[ S_{ke} = 150 \text{ ft}^2 \]

This corresponds to \( W_{ke} = 680 \text{ lbs} \) which has been assumed to be included in the engine weight. Closer weight estimates may reveal that this assumption be re-evaluated.
Figure 2.3.4. Longitudinal X-Plot for the 100-PAX Twin Body Design.
Step 4. Prepare a directional $C_n$-plot for the airplane.

Table 1 provides the c.g. data.

The $C_{n_{e}}(\xi)$ of the $C_n$-plot follows from:

$$C_{n_{e}} = C_{n_{e,\text{we}}} + C_{n_{e,v}}(\xi_{v}/\xi)(\eta_{v}/\eta)$$  \hspace{1cm} (7)

From the preliminary engine out computations of 9/26/86,

$$C_{n_{e,v}} = 2.14 \text{ rad}^{-1} \quad \xi_{v} = 923 \text{ ft}^{2}$$

$$X_{v_{e}} = 41.3 \text{ ft} \quad b = 118 \text{ ft}$$

From *Methods For Estimating Stability And Control Derivatives Of Conventional Subsonic Airplanes*,

$$C_{n_{e,\text{we}}} = C_{n_{e,v}} + C_{n_{\theta_{e}}}$$  \hspace{1cm} (8)

$$C_{n_{\theta_{e}}} \sim 0: \text{ The wing contribution is very small except of high angles of attack.}$$

$$C_{n_{\theta_{e}}} = -57.3 \frac{K_{n}}{K_{R_{e}}} \frac{2S_{e_{w_{e}}}}{S} \frac{l_{e}}{b} (\text{rad}^{-1})$$  \hspace{1cm} (9)

where,

$$S_{e_{w_{e}}} = \text{side body area} = 624 \text{ ft}^{2}$$

$$l_{b} = 94.6 \text{ ft}$$

$$x_{m} / l_{b} = 0.52$$

$$\frac{l_{b}^{2}}{S_{e_{w_{e}}}} = 14.3$$

$$h_{1} = 98 \text{ in.}$$

$$h_{2} = 89 \text{ in.}$$

$$w = 98 \text{ in.}$$

$$h / w = 1.0$$

$$K_{n} = 0.001$$

$$R_{s_{f}} = \frac{\rho V l_{f}}{\mu}$$  \hspace{1cm} (10)
Thus,
\[ R_k = 152 \times 10^6 \text{ at take-off (V = 150 knots)} \]
\[ R_k = 187 \times 10^6 \text{ at cruise (M = 0.7 at 35,000 ft)} \]

Since cruise \( R_k \) is larger,
\[ K_{R_k} = 2.05 \]
\[ C_{n_{\phi e}} = -(57.3)(0.001)(2.05)(634/923)(9.4/x_i^{1/3}) \times 2 \]
\[ C_{n_{\phi e}} = -0.129 \text{ rad}^{-1} \]

and
\[ C_{n_{\phi}} = -0.129 + 0.749(S_v/S) \]

**Table 3: Directional Stability For Various Tail Areas.**

<table>
<thead>
<tr>
<th>( S_v ) ft(^2 )</th>
<th>( S_v/S )</th>
<th>( C_{n_{\phi e}} ) rad(^{-1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.108</td>
<td>-0.048</td>
</tr>
<tr>
<td>200</td>
<td>0.217</td>
<td>0.039</td>
</tr>
<tr>
<td>300</td>
<td>0.325</td>
<td>0.114</td>
</tr>
</tbody>
</table>

Figure 2.5.5 is the related graph.

Step 5. Determine whether or not the airplane being designed needs to have 'inherent' or 'de facto' directional stability.

This airplane will be inherently stable.

Step 6. Assume that the overall level of directional stability must be,
\[ C_{n_{\phi e}} = 0.0573 \text{ rad}^{-1} \]

From Figure , this corresponds to
\[ S_v = 230 \text{ ft}^2 \]
Figure 2.55, 100-PAX TWIN BODY
DIRECTIONAL X- PLOT.

\[ C_{\alpha} = 0.0573 \text{ rad}^{-1} \]

Vertical Tail Area, \( S_v \text{ ft}^2 \)

Directional Stability, \( C_{n\alpha} \text{ rad}^{-1} \)
Step 7. Determine the critical engine-on yawing moment from:

\[ N_{\text{crit}} = T_{\text{e}} \cdot V_e \]  \hspace{1cm} (11)

where the calculations done on 9/25/86,

\[ T_{\text{e}} = 24,700 \text{ lps} \]

\[ V_e = 7 \text{ ft/s (minimum)} \]

\[ N_{\text{crit}} = 172,700 \text{ ft lps}. \]

Step 8. Determine the value of drag induced yawing moment due to the inoperative engine from:

\[ N_D = 0.44 \cdot N_{\text{crit}} \]  \hspace{1cm} (12)

\[ N_D = 69,100 \text{ ft lps} \]

Step 9. Calculate the maximum allowable \( V_{mc} \) from:

\[ V_{mc} = 1.2 \cdot V_e \]

where

\[ V_e = 172 \text{ ft/s} \]

\[ V_{mc} = 206 \text{ ft/s} \]

Step 10. Calculate the rudder deflection required to hold the engine out condition at \( V_{mc} \) from:

\[ \delta_R = \left( N_D + N_{\text{crit}} \right) / \bar{q}_{mc} \cdot S \cdot b \cdot C_{r6R} \]  \hspace{1cm} (13)

where

\[ \bar{q}_{mc} = 50.4 \text{ psf} \]

\[ S = 922 \text{ ft}^2 \]

\[ b = 118 \text{ ft} \]

\[ \delta_R = 0.044 \frac{C_{r6R}}{C_{n6R}} \]

**Original Page is Poor Quality**
$C_{n_{\delta R}}$ may be computed from

$$C_{n_{\delta R}} = -C_{y_{\delta R}} \left( \frac{l v \cos \alpha + Z v \sin \alpha}{b} \right) \quad (14)$$

where

- $l v = 40.5$ ft.
- $Z v = \text{N.A.}$
- $b = 118$ ft.
- $\alpha = 0^\circ$ (assumed to be small)

thus,

$$C_{n_{\delta R}} = -C_{y_{\delta R}} \left( 0.343 \right)$$

$C_{y_{\delta R}}$ can be calculated from

$$C_{y_{\delta R}} = C_{l_{av}} \left[ \frac{(\alpha_{\delta})_{c_l}}{(\alpha_{\delta})_{c_{l'}}} \right] (\alpha_{\delta})_{c_l} K' K_b \frac{S_v}{S} \quad (15)$$

where

- $C_{l_{av}} = 2.14 \text{ rad}^{-1}$
- $(\alpha_{\delta})_{c_l} = 1.14$
- $(\alpha_{\delta})_{c_{l'}}$
- $(\alpha_{\delta})_{c_l} = -0.7$
- $K' = 0.65$
- $K_b = 1.0$

thus

$$C_{y_{\delta R}} = -0.0012 (S_v)$$

and

$$C_{n_{\delta R}} = 0.0004 S_v$$
where

\[ C_{100} = 0.0004(\text{SV}) \]

\[ C = \frac{107}{\text{SV}^2} \]

<table>
<thead>
<tr>
<th>( \text{SV} )</th>
<th>( 25 )</th>
<th>( 30 )</th>
<th>( 35 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha )</td>
<td>122</td>
<td>102</td>
<td>88</td>
</tr>
</tbody>
</table>

Thus, the maximum vertical tail area required is,

\[ S_V = 122 \text{ ft}^2 \]
N.5 Class I Drag Polar Calculations

This section provides the calculations for the 100 passenger twin body Class I drag polars.
Step 1. List all airplane components which contribute to wetted area, compute the wetted area of these components. Find the sum, $S_{\text{wet}}$.

The components that contribute to wetted area are:
1. Fuselage
2. Wing
3. Empennage
4. Nacelles
5. Pylons

1. Wetted Area for Planform.

The wetted area of the planform can be found from:

$$S_{\text{wet,plf}} = 2 S_{\text{exp,plf}} \left\{ 1 + 0.25 (t/c)_r (1 + 2 \gamma)/(1 + \lambda) \right\}$$

where,

$$S_{\text{exp,plf}} = \frac{b_{\text{exp}} c_{\text{exp}}}{2} (1 + \lambda)$$

$$= (38.1/2)(9.17)(1.45) + (10 \times 25)$$

$$= 503.1 \text{ ft}^2$$

$(t/c)_r = 0.13$ ; $\gamma = 1.3$ ; $\lambda = 0.4$

thus

$$S_{\text{wet,plf}} = 1042 \text{ ft}^2$$

For the horizontal tail,

$$S_{\text{exp}} = 102 \text{ ft}^2 + 201 \text{ ft}^2$$

$(t/c)_r = 0.12$ ; $\gamma = 1.2$ ; $\lambda = 0.5$

$$S_{\text{wet,hor}} = 625 \text{ ft}^2$$

For the vertical tail,

$$S_{\text{exp}} = 280 \text{ ft}^2$$

$(t/c)_r = 0.13$ ; $\gamma = 1.08$ ; $\lambda = 0.50$

$$S_{\text{wet,ver}} = 567 \text{ ft}^2$$
2. Wetted Area for Fuselages.

For fuselages with cylindrical mid-sections:

\[ \text{Swet}_{\text{fus}} = \pi D_f \lambda_f \left( \frac{1 - 2}{\lambda_f} \right)^{1/2} \left( 1 + \frac{1}{\lambda_f^2} \right) \]

where

\[ \lambda_f = 11.7 \text{, the fuselage fineness ratio} \]

\[ \text{Swet}_{\text{fus}} = \pi \left( 8.08 \right) \left( 99.6 \right) \left( 1 - \frac{2}{11.7} \right)^{1/2} \left( 1 + \frac{1}{11.7^2} \right) \]

\[ \text{Swet}_{\text{fus}} = 2 \times \text{Swet}_{\text{fus}} \text{ (twin body)} \]

\[ \text{Swet}_{\text{fus}} = 4270 \text{ ft}^2 \]

3. Wetted Area for Nacelles.

The nacelle area will be estimated by:

\[ \text{Swet}_{\text{nac}} = \pi \text{ length} \times \text{diameter} \]

\[ = \pi \left( 12.5 \right) \times \left( 5.0 \right) \times 2 \]

\[ \text{Swet}_{\text{nac}} = 393 \text{ ft}^2 \]

4. Pylon Wetted Area.

\[ \text{Swet} = 2 \times \text{S}_{\text{expplf}} \left[ 1 + 0.25 (t/c)_r \left( 1 + \frac{\lambda}{1 + \lambda} \right) \right] \]

where,

\[ \lambda = 1 \text{, } (t/c)_r = 0.12 \text{, } \lambda = 1.0 \]

\[ \text{S}_{\text{exp}} = 153 \text{ ft}^2 \]

thus

\[ \text{Swet} = 315 \text{ ft}^2 \]
5. Summary of Wetted Areas.

<table>
<thead>
<tr>
<th>Component</th>
<th>Wetted Area ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing</td>
<td>1042</td>
</tr>
<tr>
<td>Horizontal Tail</td>
<td>625</td>
</tr>
<tr>
<td>Vertical Tail</td>
<td>567</td>
</tr>
<tr>
<td>Fuselage</td>
<td>4270</td>
</tr>
<tr>
<td>Engine Nacelles</td>
<td>395</td>
</tr>
<tr>
<td>Engine Pylons</td>
<td>115</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>7212 ft²</strong></td>
</tr>
</tbody>
</table>

Step 2. Using figures 3.21 of Part I find the equivalent parasite area, 'f' of the airplane.

\[ f = 17.0 \text{ ft}^{-2} \quad (C_f = 0.0025) \]

Step 3. Determine the 'clean' zero lift drag coefficient:

\[ C_{D_0} = 17.0 / 923 = 0.0184 \]

Step 4. Find the compressibility drag increment of the airplane from Figure 12.7:

\[ \Delta C_{D_0} = 0.0002 \quad \text{for compressibility} \]

Step 5. The following drag increments will be assumed:

<table>
<thead>
<tr>
<th>Configuration</th>
<th>( \Delta C_{D_0} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takeoff gear</td>
<td>0.015</td>
</tr>
<tr>
<td>Landing gear</td>
<td>0.015</td>
</tr>
<tr>
<td>Landing Flaps</td>
<td>0.075</td>
</tr>
</tbody>
</table>

Step 6. Determine the drag polars.

**Take-off:** \( C_D = 0.0334 + 0.0265 \ C_L^2 \)

\[ C_{D_0} = 0.0334 \quad \left( \frac{L}{D}_{\text{max}} = 16.8 \right) \]
\[ \epsilon = 0.80 \quad A = 15 \]

**Cruise:** \( C_D = 0.0186 + 0.0250 \ C_L^2 \)

\[ C_{D_0} = 0.0186 \quad \left( \frac{L}{D}_{\text{max}} = 23.2 \right) \]
\[ \epsilon = 0.85 \quad A = 15 \]
Landing: \( C_D = 0.1084 + 0.0265 \, \alpha^2 \)
\[ C_D = 0.1084 \]
\[ \alpha = 0.8 \]
\[ \lambda = 15 \]

Step 7. Determine Cruise L/D.

Assuming \( C_{L_{cruise}} = 0.3 \)

\( (L/D)_{cr} = 14.4 \)

By taking a 10% reduction in \( C_D \)

\( (L/D)_{cr} = 15.8 \)
N.6 Class I Inertia Calculations

The following provides the Class I inertia calculations for the 100 passenger twin body design.
Step 1. Evaluate $I_{xx}$.

$I_{xx}$ will be calculated later after completion of class II weight and balance. Class I methods are not accurate enough for the twin body configuration.

Step 2. Evaluate $I_{yy}$ and $I_{zz}$.

$W_{To} = 46,758$ lbc

$W_{Oe} = 46,758$ lbc

$k = 118$ ft

$L = 104$ ft

$e = 111$ ft

The non-dimensional radius for this airplane about the $y$-axis is assumed to be

$R_y = 0.4$ (Table B7a, Part V)

and about the $z$-axis,

$R_z = 0.5$

The inertias can be calculated from

$I_{yy} = L^2 W (R_y)^2/4g$  \hspace{1cm} (1)

$I_{zz} = (e^2 W (R_z)^2/4g + md^2) \times 2$  \hspace{1cm} (2)

Equation (2) assumes that $R_z$ applies to each body. Thus, the inertia is calculated for each body and then translated to the airplane e.g., $d = 16.7$ ft and $W_{oe} = 23,069$ lbs, $W_{to} = 40,258$ lbs for each body.

At $W_{To}$:

$I_{yy} = 1.082 \times 10^6$ slug ft$^2$

$I_{zz} = 2.623 \times 10^6$ slug ft$^2$

At $W_{Oe}$:

$I_{yy} = 6.199 \times 10^5$ slug ft$^2$

$I_{zz} = 1.505 \times 10^5$ slug ft$^2$
Step 3. Compare inertia with known data.

The figures on the following pages show how the 100 passenger twin body compares with existing data.

$I_{yy}$ may be a little high; however, the engine pylons may validate the higher $I_{yy}$ assumed.

$I_{zz}$ appears to be double that of existing conventional configurations—for a good reason. The twin body design validates the $I_{zz}$ values assumed.
APPENDIX D
PRELIMINARY DESIGN
WING STRUCTURAL WEIGHT CALCULATIONS
FOR
50 PASSENGER AND 100 PASSENGER
COMMUTER AIRPLANES
TABLE OF CONTENTS

1. WING WEIGHT CALCULATIONS

2. RESULTS OF WING WEIGHT CALCULATIONS
1. WING WEIGHT CALCULATIONS

DETERMINATION OF STRUCTURAL WING WEIGHT FOR 50 PASSENGER COMMUTER

From section 5.1.2.1, GD (General Dynamics) methodology was used in determining the wing weight estimations for commercial transport airplanes. The following equation will illustrate this methodology.

\[
W_w = \frac{0.00428 (S)^{0.48} (A)^{0.43} (M_w)^{0.84} (\lambda)_{0.14}}{(100 (t/c)_{MAX})^{0.76} (\cos A_{1/2})^{1.54}}
\]

Note: This equation is only valid for the following parameters ranges.

- \( M = 0.4-0.8 \)
- \( (t/c)_{MAX} = 0.08-0.15 \)
- \( A = 4-12 \)

Through research of airplanes with similar performance requirements the following assumptions were made for the 50 passenger airplane.

- \( W_{TO} = 45,000 \) lbs
- \( S = 600 \) ft
- \( \lambda = 0.3 \)
The design limit load factor, \( n \), was determined from equation 4.13 of Reference 1, which is as follows:

\[
\eta_{um} \geq 2.1 + \left( \frac{24,000}{W_{to} + 10,000} \right)
\]

Exceptions

\( n_{um} \) need not be greater than 3.8
\( n_{um} = 4.4 \) for utility airolanes
\( n_{um} = 6.0 \) for acrobatic airolanes

where:

\[
\eta_{ut} = 1.5(n_{um})
\]

2. RESULTS OF WING WEIGHT CALCULATIONS

For the 50 passenger commuter

\( \eta_{ut} = 3.80 \)

For the 100 passenger commuter (\( W = 110,000 \) lbs)

\( \eta_{ut} = 3.45 \)

However, one should keep in mind the influence of the negative ultimate load factor, \( n_{um} \). In the weight estimations this value isn't critical but from a structural analysis (the critical mode of failure) view this factor can be the dominating driver.
### Table 2.1 50 Passenger Commuter

\( w_0 = 45,000 \text{ lb}, S = 600 \text{ ft}^2, \lambda = 0.3, \left( \frac{t}{c} \right)_{\text{MAX}} = 0.15 \)

<table>
<thead>
<tr>
<th>ASPECT RATIO</th>
<th>WEIGHT ( \times 10^3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>1.81 1.87 1.89 1.98 2.09 2.25</td>
</tr>
<tr>
<td>9</td>
<td>2.04 2.07 2.14 2.23 2.36 2.53</td>
</tr>
<tr>
<td>10</td>
<td>2.26 2.30 2.37 2.47 2.62 2.81</td>
</tr>
<tr>
<td>11</td>
<td>2.49 2.53 2.61 2.72 2.88 3.09</td>
</tr>
<tr>
<td>12</td>
<td>2.71 2.76 2.85 2.97 3.14 3.37</td>
</tr>
<tr>
<td>13</td>
<td>2.94 2.99 3.08 3.22 3.40 3.65</td>
</tr>
<tr>
<td>14</td>
<td>3.17 3.22 3.32 3.46 3.66 3.93</td>
</tr>
</tbody>
</table>

### Table 2.2 100 Passenger Commuter

\( w_0 = 110,000 \text{ lb}, S = 1000 \text{ ft}^2, \lambda = 0.3, \left( \frac{t}{c} \right)_{\text{MAX}} = 0.15 \)

<table>
<thead>
<tr>
<th>ASPECT RATIO</th>
<th>WEIGHT ( \times 10^3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>4.52 4.60 4.74 4.94 5.23 5.61</td>
</tr>
<tr>
<td>9</td>
<td>5.08 5.17 5.33 5.56 5.88 6.31</td>
</tr>
<tr>
<td>10</td>
<td>5.65 5.75 5.92 6.18 6.53 7.01</td>
</tr>
<tr>
<td>11</td>
<td>6.21 6.32 6.51 6.80 7.19 7.71</td>
</tr>
<tr>
<td>12</td>
<td>6.78 6.90 7.11 7.41 7.84 8.41</td>
</tr>
<tr>
<td>13</td>
<td>7.34 7.47 7.70 8.03 8.49 9.11</td>
</tr>
<tr>
<td>14</td>
<td>7.91 8.05 8.29 8.65 9.15 9.81</td>
</tr>
</tbody>
</table>