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A STUDY OF COMMUTER AIRPLANE
DESIGN OPTIMIZATION

Third Status Report
KU-FRL 313-4

This work was performed under
NASA Grant NSG-2145

31 August 1977

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of Engineering

Approved by: J. Roskam, Director
Flight Research Laboratory
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<td>A</td>
<td>Area, Aspect ratio</td>
<td>ft², in²</td>
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<tr>
<td>$A_{eff}$</td>
<td>Effective aspect ratio</td>
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</tr>
<tr>
<td>a</td>
<td>Constant in regression formula</td>
<td></td>
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<tr>
<td>b</td>
<td>Constant in regression formula</td>
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<tr>
<td>$b_f$</td>
<td>Maximum fuselage width</td>
<td>ft</td>
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<td>$b_H$</td>
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<td>$C_{D0}$</td>
<td>Zero-lift drag coefficient</td>
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<tr>
<td>$C_{D_{0B}}$</td>
<td>Fuselage zero-lift drag coefficient</td>
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<tr>
<td>$C_f$</td>
<td>Skin friction drag coefficient</td>
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</tr>
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<td>$C_{f_B}$</td>
<td>Body skin friction drag coefficient</td>
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<tr>
<td>$C_{L_{a}}$</td>
<td>Lift curve slope</td>
<td>radians⁻¹</td>
</tr>
<tr>
<td>$C_{m_{a}}$</td>
<td>Pitching moment due to angle of attack</td>
<td>radians⁻¹</td>
</tr>
<tr>
<td>$C_{n_{\beta}}$</td>
<td>Yawing moment derivative due to sideslip</td>
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<td>$\bar{C}$</td>
<td>Mean geometric chord</td>
<td>ft, in</td>
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<tr>
<td>D</td>
<td>Cabin diameter</td>
<td>ft, in</td>
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<tr>
<td>$D_{C0}$</td>
<td>Outside cabin diameter</td>
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<tr>
<td>$d\theta$</td>
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<td>Tail cone wetted area correction factor</td>
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<td>Empennage weight factor</td>
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<td>$F_V$</td>
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<td>$H$</td>
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<td>$H$</td>
<td>Total pressure increase</td>
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<td>$h$</td>
<td>Height; Inside body height</td>
<td>ft, in</td>
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<td>Baggage compartment height, wall side</td>
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<td>$J_{eff}$</td>
<td>Effective advance ratio for propellers in perturbed flow</td>
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<td>$J_{is}$</td>
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<td>$K_C$</td>
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<td>Symbol</td>
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<td>( l_c )</td>
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<td>Distance from wing quarter chord to horizontal tail quarter chord</td>
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<td>Seat pitch</td>
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<td>( l_u )</td>
<td>Utility section (cabin) length</td>
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<td>Cabin length for passenger seating</td>
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<td>( l_V )</td>
<td>Vertical tail moment arm</td>
<td>ft, in</td>
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<tr>
<td>( M )</td>
<td>Mach number</td>
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<td>( M.A.C. )</td>
<td>Mean aerodynamic chord</td>
<td>ft, in</td>
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<tr>
<td>( m )</td>
<td>Slope of line, number of radial segments</td>
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<td>( N_A )</td>
<td>Number of aisles</td>
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<td>( N_S )</td>
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<td>( r_{b1} )</td>
<td>Cone ( N_1 ) radius, bottom</td>
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<td>Cone ( N_2 ) radius, bottom</td>
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<td>Cabin radius for circular cabin</td>
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<td>Predicted outside body radius</td>
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<td>$r_{bt}$</td>
<td>Tail cone radius, bottom</td>
<td>in</td>
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<td>$r_{t1}$</td>
<td>Cone N1 radius, top</td>
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<tr>
<td>$r_{t2}$</td>
<td>Cone N2 radius, top</td>
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<td>$r_{tc}$</td>
<td>Cabin radius, top</td>
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<td>$r_{tt}$</td>
<td>Tail radius, top</td>
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<td>$S_{B_s}$</td>
<td>Body side area</td>
<td>ft$^2$</td>
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<td>$S_{EMP}$</td>
<td>Empennage planform area</td>
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<td>$S_G$</td>
<td>Gross shell area</td>
<td>ft$^2$</td>
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<td>$S_H$</td>
<td>Horizontal tail area</td>
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<td>Vertical tail area</td>
<td>ft$^2$</td>
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<td>$S_{WET_B}$</td>
<td>Fuselage wetted area</td>
<td>ft$^2$</td>
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<tr>
<td>$(S_{WET})_{BODY}$</td>
<td>Fuselage wetted area</td>
<td>ft$^2$</td>
</tr>
<tr>
<td>$(S_{WET})_{Cabin}$</td>
<td>Cabin wetted area</td>
<td>ft$^2$</td>
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<td>$S_{WETH}$</td>
<td>Horizontal tail wetted area</td>
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<td>$(S_{WET})_{NOSE}$</td>
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<td>Empennage wetted area</td>
<td>(\text{ft}^2)</td>
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<tr>
<td>(S_{\text{WET}_V})</td>
<td>Vertical tail wetted area</td>
<td>(\text{ft}^2)</td>
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<tr>
<td>(S_{\text{Wing}})</td>
<td>Wing area</td>
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<tr>
<td>(T_C)</td>
<td>Apparent propeller thrust-loading</td>
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<tr>
<td>(q)</td>
<td>coefficient</td>
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<tr>
<td>(t/c)</td>
<td>Thickness ratio</td>
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<tr>
<td>(V_1)</td>
<td>Velocity increase far behind propeller</td>
<td>(\text{ft/sec})</td>
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<tr>
<td>(V_R)</td>
<td>Resultant velocity about a body</td>
<td>(\text{ft/sec})</td>
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<td>(W_{\text{EMP}})</td>
<td>Empennage weight</td>
<td>(\text{lbs})</td>
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<tr>
<td>(W_{\text{F}})</td>
<td>Fuselage shell weight</td>
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</tr>
<tr>
<td>((W_{\text{GR}}))'</td>
<td>Adjusted gross weight</td>
<td>(\text{lbs})</td>
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<td>(W_H)</td>
<td>Horizontal tail weight</td>
<td>(\text{lbs})</td>
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<tr>
<td>((W_{\text{GROSS}}))_i</td>
<td>Total gross weight for i'th tail cone/empennage configuration</td>
<td>(\text{lbs})</td>
</tr>
<tr>
<td>(W_V)</td>
<td>Vertical tail weight</td>
<td>(\text{lbs})</td>
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<td>(W)</td>
<td>Unit seat width</td>
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</tr>
<tr>
<td>(W_A)</td>
<td>Aisle width</td>
<td>(\text{ft, in})</td>
</tr>
<tr>
<td>(w_c)</td>
<td>Inside cabin width</td>
<td>(\text{ft, in})</td>
</tr>
<tr>
<td>(W_{cb})</td>
<td>Crewbox width</td>
<td>(\text{ft, in})</td>
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CHAPTER 1 INTRODUCTION

This report documents the research accomplished from May 16, 1976 through July 31, 1977 under the funding of NASA Grant NSG-2145. The research conducted was concerned with the design optimization of short haul and commuter airplanes as proposed in References 1 and 2. The intent of the research was to look at the problem of commuter airplane configuration design for the minimization of Direct Operating Costs (DOC). A more detailed explanation of the purpose and objectives of this project is provided in the following section. The status of the research and finances of the project are discussed in Section 1.2.

1.1 Purpose and Objectives

It was proposed to look at the problem of commuter airplane configuration design from the following viewpoints:

- Assume that a specific cabin volume is needed to meet some mission criterion. This will be called a utility constraint. The investigation will focus on commuter type airplanes with a crew of two and a passenger load up to approximately thirty.

- Assume that specific stability and control requirements must be met. These will be called stability and control constraints.

- Assume that specific mission profiles must be flown. These will be called mission constraints.

- Assume that specific performance (for example, field length, minimum speed, single-engine climb, etc.) requirements must be met. These will be called performance constraints. Attention will be focussed on field lengths in the 2500 ft. to 4500 ft. range.

The problem then was to design an airplane configuration which would have the lowest DOC. Figure 1.1 illustrates the problem. The approach taken to the solution of this problem was along the following lines:
Given:

1) Cabin-Utility Constraint
2) Mission Constraint
3) Stability and Control Constraints
4) Performance Constraints

Find:

The Configuration Which Minimizes D.O.C.

Figure 1.1 Illustration of the Design Problem
a) Investigate methods for determining the fuselage shape and size which would yield minimum fuselage drag and weight. The fuselage was to be treated as three separate sections (the nose, the cabin, and the tail cone), and methods for the design of each section were to be considered. Chapter 2 discusses the configuration design approaches considered for the fuselage.

b) Determine how the methods of item a) might be integrated into the NASA-Ames General Aviation Synthesis Program (GASP). The GASP was chosen to be the most effective way to apply configuration design methods to the overall preliminary airplane design process. Chapter 3 discusses the ways in which the methods of item a) were to be integrated into the GASP.

c) Determine the critical stability and control constraints which needed to be integrated simultaneously into the GASP. Chapter 5 discusses the stability and control constraints that were considered and explains the ways in which they were to be integrated into the GASP.

d) Perform a short study of wing sizing methods to consider trade-offs in wing loading for effects on performance, ride qualities, etc. One method in particular that was to be considered for wing sizing was the method proposed in Reference 3. Also to be considered was a rational approach to wing placement, bearing in mind weight and balance, stability and control, passenger acceptability, and feasibility of associated structural arrangements. These studies are discussed in Chapter 3.

e) Consider the problem of estimating the drag of airplane components submerged in a propeller slipstream. This problem is discussed in Chapter 4.

As has been stated, the GASP was to be the medium through which all of the configuration design methodologies were to be applied. Unfortunately particular difficulty was encountered in getting a version of the GASP to run on the University of Kansas Honeywell 66/60 computer. For this reason it has not been possible to complete the integration of the design methodologies into GASP. A complete discussion of the transliteration process is presented in Chapter 5.
1.2 Research and Financial Status

1.2.1 Research Status

At the time of this report much of the work outlined in the objectives has been completed. The fact that the GASP is still inoperational has provided the greatest set-back. Revisions to the GASP to include the newly developed methods could not be made without first being assured that the GASP could be operated properly in its existing form. Also, more research needs to be conducted in the area of stability and control methods. Table 1.1 summarizes the status of each research area. Also, Table 1.1 refers to the chapters where each facet of the research will be discussed.

1.2.2 Financial Status

Tables 1.2 and 1.3 present the budgets for the two phases of the project as proposed in References 1 and 2. Together, they represent a total allocation of $50,590 through NASA Grant NSG-2145. Although a complete breakdown of expenses through July 31, 1977 was not available at the time of this report, it was possible to arrive at an estimate as to the remaining balance as of that date. It is estimated that as of July 31, 1977 the balance of funds remaining in NASA Grant NSG-2145 will be approximately $100.
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<tr>
<td></td>
<td>1) Continued Cabin arrangement &amp; Baggage Compartment Studies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c) Wetted Area Studies</td>
<td>3) KU-FRL 901; Preliminary correlations Chapter 4, this report</td>
<td>3) Correlation of Actual Wetted Areas with FUSE-computed Areas Chapter 4, this report</td>
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<tr>
<td>2) Weight Estimation Methods</td>
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<td>a) Torenbeek's Method</td>
<td>4) KU-FRL 902; included in Roskam/Fillman Method Program Chapter 2, this report</td>
<td>4) Checking use of GASP Weight Estimation Methods</td>
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<td>ITEMS PENDING</td>
<td>ITEMS TO BE PROPOSED</td>
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<td>PROPOSAL I</td>
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<td>PROPOSAL III</td>
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<tr>
<td>3) Stability Constraints</td>
<td>2) Analysis of GASP designs</td>
<td>5) KU-FRL 902; Empennage Sizing by $C_m$ &amp; $C_n$ in the Roskam/Filman Method</td>
<td>5) Looking at ways to replace GASP V methods, to include inertia est. to enable dynamic stability analysis, and to locate wing</td>
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<td>3) Fuselage Config. Studies</td>
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<tr>
<td>a) Nose section model</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) Cabin sizing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8) KU-FRL 313-3; FUSE</td>
<td></td>
<td></td>
<td>7) Use of FUSE with NCSU BODY Program to Analyze Nose</td>
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<tr>
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<tr>
<td>ITEMS AND/OR OBJECTIVES</td>
<td>PROPOSAL I</td>
<td>PROPOSAL II</td>
<td>PROPOSAL III</td>
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<td>------------</td>
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<tr>
<td>4) Wing Config.</td>
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<tr>
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<td>i0) Chapter 3, this report</td>
<td>8) Loftin's Method to be Considered</td>
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</tr>
<tr>
<td>b) Placement</td>
<td>ii) Chapter 3, this report</td>
<td>9) Considering combination of GASP and Torenbeek's method</td>
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</tr>
<tr>
<td>5) Develop algorithms for GASP</td>
<td>12) Chapter 3, this report</td>
<td>10) Finding that it is possible to simply amend GASP methods</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2) Complete addition of developed algorithms into GASP and check them out</td>
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</table>
Table 1.2 Proposed Budget

May 16, 1976 - December 15, 1976

<table>
<thead>
<tr>
<th></th>
<th>NASA</th>
<th>KU</th>
<th>TOTAL</th>
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<tr>
<td><strong>Salaries &amp; Wages</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Principal Investigator (Roskam)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20% for 4 mos. academic*</td>
<td>1,271</td>
<td>1,271</td>
<td>2,542</td>
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<tr>
<td>67% for 3 mos. summer</td>
<td>5,807</td>
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<td>5,807</td>
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<tr>
<td>Research Assistants (3 1/2)</td>
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<tr>
<td>50% for 7 months</td>
<td>9,800</td>
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<tr>
<td>Secretary</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2 man-months</td>
<td>1,000</td>
<td>0</td>
<td>1,000</td>
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<tr>
<td><strong>Total Salaries &amp; Wages</strong></td>
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<tr>
<td><strong>Fringe Benefits</strong></td>
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<td></td>
<td></td>
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<tr>
<td>16% Faculty &amp; Staff</td>
<td>1,293</td>
<td>203</td>
<td>1,496</td>
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<tr>
<td>7% Students</td>
<td>686</td>
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<td>686</td>
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<tr>
<td>Computer</td>
<td>2,000</td>
<td>0</td>
<td>2,000</td>
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<tr>
<td>Supplies &amp; Reproduction</td>
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<td>0</td>
<td>200</td>
</tr>
<tr>
<td>Telephone</td>
<td>200</td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>Travel (2 trips to Ames)</td>
<td>750</td>
<td>0</td>
<td>750</td>
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<tr>
<td><strong>Total Direct Costs</strong></td>
<td>23,007</td>
<td>1,474</td>
<td>24,481</td>
</tr>
<tr>
<td><strong>Indirect Costs - 53.6% of Total S &amp; W</strong></td>
<td>9,583</td>
<td>681</td>
<td>10,264</td>
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<tr>
<td><strong>Total Proposed Costs</strong></td>
<td>32,590</td>
<td>2,155</td>
<td>34,745</td>
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</tbody>
</table>

*Principal Investigator’s academic time cost shared by KU and NASA equally. Each paying only 10% for 4 mos. academic time = 20%.

<table>
<thead>
<tr>
<th>Salary Schedule</th>
<th>FY76</th>
<th>FY77</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roskam</td>
<td>2,889/mo.</td>
<td>3,178/mo.</td>
</tr>
<tr>
<td>Research Assistant</td>
<td>800/mo.</td>
<td>NA</td>
</tr>
<tr>
<td>Secretary</td>
<td>500/mo.</td>
<td>NA</td>
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</table>
Table 1.3 PROPOSED BUDGET
January 1, 1977 - June 30, 1977

<table>
<thead>
<tr>
<th>Direct Costs</th>
<th>NASA</th>
<th>KU</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Salaries &amp; Wages</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Principal Investigator - Roskam</td>
<td>$416</td>
<td>$417</td>
<td>$833</td>
</tr>
<tr>
<td>25% for 1 mo. academic FY 77</td>
<td>2,500</td>
<td>0</td>
<td>2,500</td>
</tr>
<tr>
<td>75% for 1 mo. summer FY 77</td>
<td>3,038</td>
<td>0</td>
<td>3,038</td>
</tr>
<tr>
<td>Graduate Research Assistant</td>
<td>900</td>
<td>0</td>
<td>900</td>
</tr>
<tr>
<td>75% for 4.5 mos. academic 77</td>
<td>337</td>
<td>0</td>
<td>337</td>
</tr>
<tr>
<td>Undergraduate Research Assistants</td>
<td>2,625</td>
<td>0</td>
<td>2,625</td>
</tr>
<tr>
<td>75% for .5 mo. summer 77 (1 student)</td>
<td>1,050</td>
<td>0</td>
<td>1,050</td>
</tr>
<tr>
<td>100% for .5 mo. summer 77 (1 student)</td>
<td>350</td>
<td>0</td>
<td>350</td>
</tr>
<tr>
<td>Secretary</td>
<td>1,398</td>
<td>0</td>
<td>1,398</td>
</tr>
<tr>
<td>2.33 man-months (student)</td>
<td>12,614</td>
<td>417</td>
<td>13,031</td>
</tr>
</tbody>
</table>

| Fringe Benefits |      |    |       |
| 17% staff | 496 | 71 | 567 |
| 7% students | 679 | 0 | 679 |

| Other Direct Costs |      |    |       |
| Computer | 2,540 | 0 | 2,540 |
| Supplies and Reproduction | 400 | 0 | 400 |
| Telephone | 500 | 0 | 500 |
| Travel | 1,000 | 0 | 1,000 |

Total Direct Costs | 18,229 | 488 | 18,717 |

Indirect Costs @ 53.6% of Salaries & Wages | 6,761 | 224 | 6,985 |

Total Proposed Costs | $24,990 | $712 | $25,702 |

Less unexpended balance in NASA Grant NSG 2145 | 6,990 |

Total Proposed Costs | $18,000 |
CHAPTER 2  FUSELAGE CONFIGURATION STUDIES

As stated in Chapter 1 one of the objectives of the research program was to investigate methods for determining the fuselage shape and size which would yield minimum fuselage drag and weight. A two-phase approach was taken to meet this objective. The first phase consisted of evaluating existing methods for sizing the fuselage or, where the need arose, to develop new methods. Also included in this phase was an evaluation of existing methods for determining fuselage drag and weight. The second phase of this approach was to integrate the methods chosen as a result of the first phase into the GASP and to perform trade-offs in the fuselage configuration design to find trends from which optimum configurations might be determined. In this manner it was also hoped that it might become possible to locate critical configuration determining parameters, and eventually to develop routines to optimize the fuselage directly, for a given set of constraints. Unfortunately, because of the difficulties encountered in putting the GASP into an operational status, the second phase of the approach has not been completed at the time of this report. For this reason, this chapter is concerned primarily with the first phase - the evaluation and development of fuselage design and analysis methods.

To facilitate the fuselage design procedures, the fuselage was considered to be composed of three distinct sections - the nose cone, the cabin and the tail cone. This is illustrated in Figure 2.1. Design methods were considered for each section individually and then were integrated to provide a method to determine the overall fuselage shape and size. The methods considered for each section are discussed in the following sections of this chapter. Section 2.1 compares different methods for sizing the cabin given a specified number of passengers. Section 2.2 describes a method for sizing the nose cone and crew compartment. Section 2.3 discusses a method for determining the fuselage/empennage configuration to meet specified static stability
criteria. Section 2.4 presents the results of a study to determine baggage compartment requirements for commuter airplanes and the alternatives for satisfying those requirements. Finally a method for sizing the overall fuselage is discussed in Section 2.5.

Figure 2.1 Definition of Fuselage Sections

2.1 Cabin Arrangement

The fuselage cabin design is primarily dependent upon the number and arrangement of passengers. However, possible use of the airplane for cargo payloads, the location of the wing carry-through structure, and location of main landing-gear storage can also enter into the cabin design. Although the main emphasis of this research was to determine and evaluate methods to size the cabin for utility (i.e. passengers) constraints, a conscious attempt was made to keep other factors in mind.

Before looking at existing sizing methods, or developing any new ones, a survey was conducted to examine the dimensions of existing commuter airplane cabins. The results of this survey are presented in Table 2.1. In Table 2.1 the seating configuration is indicated in an X/Y format where the values of X and Y indicate the number of seats abreast on either side of a single cabin aisle. The sole exception to this is the Britten-Norman Trislander which has no aisle.
<table>
<thead>
<tr>
<th>No</th>
<th>Aircraft</th>
<th>Seating Config.</th>
<th>Seating Seats</th>
<th>Cabin* Width (in.)</th>
<th>Cabin* Height (in.)</th>
<th>Cabin* Length (in.)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>15</td>
<td>55</td>
<td>57</td>
<td>276</td>
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<tr>
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<td>Cessna 402</td>
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<td>7</td>
<td>56</td>
<td>51</td>
<td>174</td>
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<tr>
<td>3</td>
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<td>43</td>
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<td>62</td>
<td>57</td>
<td>306</td>
</tr>
<tr>
<td>5</td>
<td>Queen Air</td>
<td>1/1</td>
<td>7</td>
<td>52</td>
<td>57</td>
<td>108</td>
</tr>
<tr>
<td>6</td>
<td>GAF Nomad</td>
<td>1/1</td>
<td>15</td>
<td>51</td>
<td>62</td>
<td>331</td>
</tr>
<tr>
<td>7</td>
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<td>8</td>
<td>51</td>
<td>52</td>
<td>-</td>
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<td>8</td>
<td>Saunders ST-27</td>
<td>1/1</td>
<td>22</td>
<td>54</td>
<td>69</td>
<td>336</td>
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<td>60</td>
<td>60</td>
<td>264</td>
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<td>18</td>
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<td>82</td>
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<td>65</td>
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<td>480</td>
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* Inside Dimensions
** Approximate—varies with configuration
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<th>Aircraft</th>
<th>Seating Config.</th>
<th>Passenger Seats</th>
<th>Cabin* Width (in.)</th>
<th>Cabin* Height (in.)</th>
<th>Cabin** Length (in.)</th>
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<td>88</td>
<td>79</td>
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<td>GAC-100</td>
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<td>98</td>
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<td>109</td>
<td>76</td>
<td>-</td>
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<td>IAI Arava</td>
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<td>18</td>
<td>75</td>
<td>68</td>
<td>144</td>
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</tbody>
</table>

* Inside Dimensions

** Approximate—varies with configuration
Where the data were available seat, aisle and seat pitch dimensions were also examined, in addition to the inside cabin width and height dimensions. Figures 2.2 and 2.3 define the cabin and cabin seating dimensions that will be referred to throughout this section.

Figure 2.2 Definition of Cabin Dimensions

Figure 2.3 Definition of Seating Arrangement Dimensions
The cabin sizing problem is one of trading-off passenger comfort and seat-miles for drag and weight. Passenger comfort may be related to the spacing between seats. As spacing is increased, so is passenger comfort. However, as comfort, and for that matter the number of total passenger seats is increased so are the drag and the weight of the overall airplane, which tends to reduce cost-effectiveness. Although this section only deals with sizing the cabin for specified comfort levels and seating arrangements, the trade-offs will be considered to some extent in Chapter 4.

Comfort level is difficult to define. In lieu of trying to survey passengers as to what might be considered as 'comfortable' or not, and then having to extract the size-related factors from noise, vibration, ride quality, etc., it was decided to take what data were available for cabin seating arrangements and attempt to define general comfort levels. A letter from the project technical monitor at NASA-Ames, Tom Galloway (Reference 4), defined three comfort levels as shown in Table 2.2. For the most part the data available supported these values. The one exception was in the case of aisle width. A number of aircraft were found to have aisle widths lower than 16 inches. For this reason the comfort levels that will be used in this report are as presented in Table 2.3.

<table>
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<th>Table 2.2 Seating Arrangement</th>
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<table>
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<td>Single Seat Width</td>
<td>18&quot;</td>
<td>20&quot;</td>
<td>22&quot;</td>
</tr>
<tr>
<td>Seat Pitch</td>
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<td>30&quot;</td>
<td>32&quot;</td>
</tr>
<tr>
<td>Aisle Width</td>
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<td>18&quot;</td>
<td>20&quot;</td>
</tr>
<tr>
<td>Standup Headroom</td>
<td>64&quot;</td>
<td>70&quot;</td>
<td>76&quot;</td>
</tr>
</tbody>
</table>
2.1.1 Determination of Cabin Cross-Section

As was stated in Chapter 1, the GASP was to be the medium of application for all design methods that were developed under this project. The GASP presently assumes that the cabin may be represented by a right circular cylinder of constant cross-section. For the purpose of this project the constant cross-section assumption was maintained. However, the cross-section was not limited to circular shapes. The smaller commuter airplanes frequently have cabin cross-sectional shapes which are far from being circular. For this reason, circular, elliptical, and what will be referred to as rounded-rectangular shapes were considered. This report will deal with the circular and round-rectangular shapes only. The elliptically shaped cross-sections are inherently covered by the methods that will be discussed here. The geometry for the rounded-rectangular cross-sectional shapes is presented in Figure 2.4. Note that the rounded-rectangular cross-section becomes an ellipse (or circle) for \( r_{tc} \) and \( r_{bc} = 1 \).

\[
Y_t = r_c \left( \frac{W}{2} \right) \\
Y_b = r_c \left( \frac{W}{2} \right) \\
Z_t = r_c \left( \frac{H}{2} \right) \\
Z_b = r_c \left( \frac{H}{2} \right)
\]

Figure 2.4 Geometric Definition of Rounded-Rectangular Cross-sections

Table 2.3 Revised Seating Arrangement

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Minimum</th>
<th>Adequate</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seat Width</td>
<td>18&quot;</td>
<td>20&quot;</td>
<td>22&quot;</td>
</tr>
<tr>
<td>Seat Pitch</td>
<td>28&quot;</td>
<td>30&quot;</td>
<td>32&quot;</td>
</tr>
<tr>
<td>Aisle Width</td>
<td>12&quot;</td>
<td>18&quot;</td>
<td>20&quot;</td>
</tr>
<tr>
<td>Standup Headroom</td>
<td>64&quot;</td>
<td>70&quot;</td>
<td>76&quot;</td>
</tr>
</tbody>
</table>
For both circular and rounded-rectangular cross-sections the values for the inside cabin height and width were expected to be largely dependent on the seating arrangement selected and the comfort level. To help in finding the best methods for determining these two dimensions the data of Table 2.1 were plotted to correlate total passenger seats and seating arrangement with inside cabin width and height. These plots are presented as Figures 2.5 and 2.6.

From Figures 2.5 and 2.6 note first that for the range of airplanes considered there seemed to be more or less definite passenger capacities for which each seating configuration was used. Table 2.4 presents the apparent passenger capacity ranges for each seating configuration. Note also from Figure 2.5 that the cabin width ranges for each seating configuration are well defined. These are also presented in Table 2.4. The cabin heights for each seating configuration are not so well defined in Figure 2.6. This would seem to indicate that cabin height is not as dependent upon the seating arrangement as was originally expected. This will be discussed further at a later point in this section.

Table 2.4  Passenger Capacity and Cabin Width Ranges for Seating Configurations of Existing Commuter Aircraft

<table>
<thead>
<tr>
<th>Seating Config.</th>
<th>Passenger Capacity Range</th>
<th>Cabin Width Range (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1</td>
<td>0 - 22</td>
<td>43 - 62</td>
</tr>
<tr>
<td>1/2</td>
<td>15 - 33</td>
<td>62 - 96</td>
</tr>
<tr>
<td>2/2</td>
<td>30 - 60</td>
<td>88 - 109</td>
</tr>
</tbody>
</table>

It is interesting at this point to compare the cabin width ranges of Table 2.4 with the comfort levels of Table 2.3. Using values resulting from the sum of the seat widths and aisle width as estimated cabin width Table 2.5 compares the values for minimum and maximum comfort levels with the observed cabin width ranges.
Figure 2.5  Correlation of Inside Cabin Width with Number of Passengers
NOTE: Data from Table 2.1

Figure 2.6 Correlation of Inside Cabin Height with Number of Passengers

2.10
Table 2.5 would seem to indicate that the comfort level criteria are reasonable. The minimum comfort level does indicate larger cabin widths for the 1/1 and 1/2 configurations, however in a number of cases aisle width values lower than 12 inches were observed. Also it should be noted that the 43 inch cabin width was the Britten-Norman Islander which has no aisle.

<table>
<thead>
<tr>
<th>Seating Config.</th>
<th>Cabin Width Range (in.)</th>
<th>Minimum Comfort Level Cabin Width (in.)</th>
<th>Maximum Comfort Level Cabin Width (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1</td>
<td>43 - 62</td>
<td>48</td>
<td>64</td>
</tr>
<tr>
<td>1/2</td>
<td>62 - 96</td>
<td>66</td>
<td>86</td>
</tr>
<tr>
<td>2/2</td>
<td>88 - 109</td>
<td>84</td>
<td>108</td>
</tr>
</tbody>
</table>

In an attempt to derive relationships for cabin width and cabin height as a function of passenger capacity and/or seating arrangement least-squares linear and logarithmic curve fits were applied to both Figures 2.5 and 2.6. The results of these curve fit applications are presented as Figures 2.7 through 2.9. Note that the cabin width data are only presented in the "thumbprint" form. This has been done purely to add clarity to the figures. All of the curve fit calculations are based on the data of Table 2.1. Note in Figure 2.7 that the 1/1 and 2/2 configuration lines are almost parallel and that the 1/2 configuration line seems to represent a transition between the two. A linear regression analysis was performed for each seating configuration for the cabin height case but the resulting relationship reinforced the conclusion made earlier that cabin height is not very dependent upon the seating arrangement. Both of the logarithmic curve fits (Figures 2.8 and 2.9) show that cabin width and cabin height may be
Linear Regression Analysis
Seating Arrangement

- $2/2$, $w_c = 0.557 \text{ (PAX)} + 45.93$
- $1/2$, $w_c = 0.771 \text{ (PAX)} + 60.16$
- $1/1$, $w_c = 0.560 \text{ (PAX)} + 73.62$

Figure 2.7 Linear Correlation of Inside Cabin Width with Number of Passengers
Logarithmic Curve Fit

- 90% Tile
  \[ w_c = 12.45 + 28.77 \ln(PAX) \]
- Mean
  \[ w_c = 27 + 28.77 \ln(PAX) \]

Figure 2.8 Logarithmic Correlation of Inside Cabin Width with Number of Passengers
NOTE: Logarithmic Curve Fit

\[ h_c = 25.12 + 13.61 \ln \text{PAX} \]

90% Line:

\[ h_c = 32.52 + 13.61 \ln \text{PAX} \]

Seat Arrangement

- \( \approx 1/1 \)
- \( \approx 1/2 \)
- \( \approx 2/2 \)

Figure 2.9 Logarithmic Correlation of Inside Cabin Height with Number of Passengers
related to total passenger capacity.

As both cabin width and cabin height may be related to total passenger capacity but only cabin width may be easily related to the number of seats abreast, then it was thought that perhaps cabin height could be related to the cabin's other primary dimension, length. It seems reasonable, at least from a comfort point of view, that the longer the cabin, the less passengers will like having to put up with a low ceiling aisle. Figure 2.10 relates cabin height with cabin length. Figure 2.10 does seem to indicate that there is some relationship but the correlation is not as good as was expected. No further research was pursued along this line.

2.1.1.1 Existing Cross-Section Sizing Methods

Only three existing cross-section sizing methods were available for evaluation - the Boeing Vertol Method (Reference 5), the McDonnell Douglas method (Reference 6), and the GASP method. Each of these methods assumes a circular cross-section.

The Boeing Vertol method is based on the assumption that a circular cabin cross-section can be designed for a particular seating arrangement that will clear certain body-seated control points. The method was developed in the following manner. Five control points were chosen to constrain the inner cabin wall about a seated passenger as shown in Figure 2.11. Using these control points layouts for different configuration layouts were made. An empirical relationship was developed based on the number of seats abreast, seat width, number of aisles, and aisle width using the data derived from the layouts. This relationship is presented in Figure 2.12. The outside body radius was then computed as a constant percentage of the inner radius. A comparison of actual outside body radii and computed outside body radii is presented in Figure 2.13.

Although reference will be made to the McDonnell Douglas method, no actual sizing method was available. Instead the results of a study of the operational requirements for medium density air transportation were available. These results are presented in References 6, 7 and 8.
NOTE: Logarithmic Curve Fit

\[ h_c = 22.164 + 15.985 \ln(l_u) \]

\[ r^2 = 0.501 \]

Seat Arrangement
- \( \sim 1/1 \)
- \( \sim 1/2 \)
- \( \sim 2/2 \)

Figure 2.10 Logarithmic Correlation of Inside Cabin Height with Cabin Length
Figure 2.12 Empirical Relationship for Cabin Radius by the Boeing Vertol Method (Reproduced from Reference 5)
Figure 7.13 Comparison of Predicted Body Radius with Actual Body Radius for Six Commercial Aircraft (Reproduced from Reference 5)

NOTE:
\[ r_{BP} = r_C / 0.94 \]

- DC9-10
- 707-320B, 737-100
- F28
- DHC-6
- 747

Perfect Agreement
Figure 2.14 is a reproduction from Reference 8 of the cross-section developed for the baseline feederliner of the McDonnell Douglas study. The cross-section was designed not only with passenger seating in mind, but also to accept palletized cargo. The only control points specified to constrain the shape for passenger seating were at the tangent to a seven inch circle drawn about the center of the head for a 95 percentile seated man and at the top-center of the cabin. A further control point was defined at the base of the outer seat leg, six inches from the seat center line. With the seat dimensions and aisle height (i.e. cabin inside height), these points could be located and the cross-section shape determined.

Having specified three control points on the inner wall of the cabin, and defining these points relative to the cabin center point, the cabin cross-section is over-constrained. Only two constraints are required, but by having three it is possible to choose which constraints are critical in the case being considered. Equations 2.1, 2.2 and 2.3 define the inside cabin radius from each control point in terms of the seating configuration and the cabin center point:

A. **Ceiling Constraint (Control Point A):**

\[ r_c = h_c - z \]  
(2.1)

B. **Passenger Headroom Constraint (Control Point B):**

\[ r_c = \sqrt{[1/2(\text{N}_s - 1)w_s + \text{N}_a w_A]^2 + (48 - z)^2} \]  
(2.2)

C. **Floor Constraint (Control Point C):**

\[ r_c = \sqrt{[1/2(\text{N}_s - 1)w_s + \text{N}_a w_A + 6]^2 + z^2} \]  
(2.3)

where, in the above equations,

- \( \text{N}_s \) = number of seats abreast
- \( w_s \) = single seat width (in.)
- \( \text{N}_a \) = number of aisles
\[ w_A = \text{aisle width (in.)} \]

\[ z = \text{vertical location of the cabin center point with respect to the floor (in.)} \]

\[ h_c = \text{inside cabin height from the floor (in.)} \]

It is assumed that the only unknowns in equations 2.1, 2.2, and 2.3 are \( r_c \) and \( z \). The value of cabin height will be assumed to be a given comfort level value. To find the cabin radius any pair of constraints may be chosen. By then solving the resulting pair of equations for \( r_c \) the cabin is sized for those particular constraints. The third equation may then be solved to determine if the cabin radius is adequate for that constraint.

In most cases, constraints B and C will probably be critical. By solving equations 2.2 and 2.3 simultaneously for \( r_c \) these constraints can be met. However, in this case the cabin height must also become a variable. After determining the cabin radius and the center point locations, the cabin height may be checked. If the cabin height is inadequate the cabin may be sized for new constraints.

Equations 2.4, 2.5 and 2.6 provide the solutions for \( r_c \) for each constraint pair.

**Constraints A and B:**

\[
\frac{\left(\frac{w}{2}\right)^2 + (48 - h_c)^2 - 49}{2(55 - h_c)}
\] (2.4)

**Constraints A and C:**

\[
\frac{\left[\left(\frac{w}{2}\right) + 6\right]^2 + h_c^2}{2h_c}
\] (2.5)

**Constraints B and C:**

\[
\frac{-B \pm \sqrt{B^2 - 4AC}}{2A}
\] (2.6)

2.21
where

\[ A = \frac{49}{2304} - 1 \]

\[ B = -\frac{98}{2304} \left[ \frac{6}{7} \left( \frac{w}{2} \right) - \frac{2219}{14} \right] \]

\[ C = \frac{49}{2304} \left[ \frac{6}{7} \left( \frac{w}{2} \right) - \frac{2219}{14} \right]^2 + \left[ \left( \frac{w}{2} \right) + 6 \right]^2 \]

For all of the above equations:

\[ \left( \frac{w}{2} \right) = \frac{1}{2} \left[ (N_s - 1)w_s + N_Aw_A \right] \]

---

**Figure 2.14** McDonnell Douglas 30-Passenger Feederliner Cross-Section
(Reproduced from Reference 8)
Table 2.6 Cabin Widths* for the Minimum Comfort Level

<table>
<thead>
<tr>
<th>Seating Config.</th>
<th>Boeing Vertol Method</th>
<th>McDonnell Douglas Method</th>
<th>GASP Method (Outside)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1</td>
<td>69.65</td>
<td>67.04</td>
<td>60.00</td>
</tr>
<tr>
<td>1/2</td>
<td>80.97</td>
<td>79.26</td>
<td>78.00</td>
</tr>
<tr>
<td>2/2</td>
<td>93.49</td>
<td>93.53</td>
<td>96.00</td>
</tr>
</tbody>
</table>

Table 2.7 Cabin Widths* for the Adequate Comfort Level

<table>
<thead>
<tr>
<th>Seating Config.</th>
<th>Boeing Vertol Method</th>
<th>McDonnell Douglas Method</th>
<th>GASP Method (Outside)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1</td>
<td>75.79</td>
<td>72.14</td>
<td>70.00</td>
</tr>
<tr>
<td>1/2</td>
<td>89.19</td>
<td>87.00</td>
<td>90.00</td>
</tr>
<tr>
<td>2/2</td>
<td>104.06</td>
<td>103.75</td>
<td>110.00</td>
</tr>
</tbody>
</table>

Table 2.8 Cabin Widths* for the Maximum Comfort Level

<table>
<thead>
<tr>
<th>Seating Config.</th>
<th>Boeing Vertol Method</th>
<th>McDonnell Douglas Method</th>
<th>GASP Method (Outside)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1</td>
<td>79.66</td>
<td>74.90</td>
<td>76.00</td>
</tr>
<tr>
<td>1/2</td>
<td>94.96</td>
<td>91.88</td>
<td>98.00</td>
</tr>
<tr>
<td>2/2</td>
<td>112.05</td>
<td>110.77</td>
<td>120.00</td>
</tr>
</tbody>
</table>

* Cabin Width in inches
The GASP method only sizes for the outside dimension of the cabin. As with the other methods a circular cross-section is assumed with a diameter determined as in equation 2.7. The constant twelve inches are intended to account for clearances about the seats and for the structure.

\[ D = N_s \cdot w_s + N_A \cdot w_A + 12 \] (inches) \quad (2.7)

where:
- \(D\) = outside cabin diameter (inches)
- \(N_s\) = number of seats abreast
- \(N_A\) = number of aisles
- \(w_s\) = seat width (inches)
- \(w_A\) = aisle width (inches)

### 2.1.1.2 Evaluation of Cross-Section Sizing Methods

To evaluate the application of the cabin sizing methods described above to the design of short haul and commuter airplanes, it was decided to compare cabin widths computed by these methods for each comfort level with the data of Table 2.1 and Figure 2.5. As the cross-section is assumed to be circular at this point the inside cabin width, \(w_c\), may be assumed to be equal to the inside cabin diameter. Tables 2.6, 2.7, and 2.8 present the results for the minimum, adequate, and maximum comfort levels respectively. Figures 2.15, 2.16, and 2.17 plot the results of each of these tables respectively on the seating arrangement thumbprints of Figure 2.5, for each sizing method and each seating arrangement.

From Figures 2.15 through 2.17 it is apparent that the methods generally size for cabins larger than those of existing aircraft. This is especially true for the 1/1 configurations. In this case the GASP method seems to do the best job when it is taken into consideration that the GASP sizings are for outside widths. The Boeing Vertol and McDonnell Douglas methods do fairly well for the 1/2 and 2/2 seating configurations however. It is also noted that the McDonnell
NOTE:
1) Cabin Sizing Method
- Boeing (Inside)
- Douglas (Inside)
- GASP (Outside)

2) Thumbprints Indicate Actual Aircraft from Figure 2.5

Figure 2.15 Comparison of Computed Minimum Comfort Level Cabin Widths with Existing Aircraft Data
Figure 2.16 Comparison of Computed Adequate Comfort Level Cabin Widths with Existing Aircraft Data
Figure 2.17 Comparison of Computed Maximum Comfort Level Cabin Widths with Existing Aircraft Data
Douglas and Boeing Vertol methods represent very similar results in all cases.

To determine why the Boeing Vertol and McDonnell Douglas methods over-sized cabin width for the smaller seating configurations (i.e. 2 and 3 seats abreast), the extreme case was considered - the 1/1, minimum comfort configuration. The cabin was sized using both methods in Table 2.6. Figure 2.18 presents a drawing showing the resulting cross-sections and seating arrangement. Note that for the Boeing Vertol cross-section control points B, C, and D are not needed and that points A and E become the critical constraints. This results in a large amount of wasted space between the outer armrest and the cabin wall. The same occurs for the McDonnell Douglas cross-section. To provide the seated headroom constraints for these smaller seating configurations the width must be oversized.

Figure 2.19 shows the result of the GASP method which produced a cabin width which was comparable with existing aircraft. The seat used in both Figures 2.18 and 2.19 was a conceptual economy-class seat sized to the minimum comfort level dimensions of Table 2.3. The seated headroom constraint shown in Figure 2.19 is the same as that for the McDonnell Douglas method. The seven inch clearance radius is drawn about the location of the center of a 95 percentile seated man (48 inches above the floor at the seat center line). As the GASP method only sizes for the outside cabin dimension, the Boeing Vertol method for estimating structure was used to determine the inside cabin radius (See Figure 2.13). Figure 2.19 indicates that with these constraints it would be extremely difficult to fit a 95 percentile man in the cabin. Although seat dimensions for smaller seats were not readily available, it is assumed that with such a seat (i.e. lower seat height, greater nominal recline angle, etc.), such a cabin would become cramped but practical. Indeed, several aircraft such as the Gates-Learjets already do this. For a pressurized airplane where a circular cross-section means weight savings, this then would be a viable cabin sizing method.

In the case of unpressurized commuters, a better solution is
NOTE:
1) Scale in Inches
   0  10  20
2) Comfort Level: Minimum
3) Control Points
   • McDonnell Douglas
   ▲ Boeing Vertol

Figure 2.18 Boeing and Douglas Cabin Cross-sections for Minimum Comfort Level
available. The rounded-rectangular cross-section of Figure 2.4 can result in a more comfortable cabin without giving up much in the way of weight or drag. In this case, however, it may no longer be assumed that outside body width equals body height. Therefore each must be sized. The values of the round-off radii are for the most part a matter of preference.

Equation 2.8 may be used to determine the inside cabin width. In equation 2.8 it is assumed that the window-side armrest of the seat is placed directly up against the cabin wall.

$$w_c = N_{ws} w_s + N_{Aw}$$  \hspace{1cm} (2.8)

To determine the fuselage inner height (i.e. total outside body height minus structure), first a control point is established as in control point C for the McDonnell Douglas method. It is assumed that to minimize fuselage inner height, the floor is to be placed as low as this control point will allow (as shown in Figure 2.20). Using the bottom round-off radius fraction, $r_{bc}$, it should be possible to determine the necessary fuselage height. Let the height below the floor be represented as $h_f$. The inside fuselage height is then as represented in equation 2.9.

![Figure 2.20 Location of Floor Control Point for Rounded-Rectangular Cross-Sections](image-url)
The round-off shape is elliptical. Therefore at the control point:

\[
\left(\frac{2z}{hr_{bc}}\right)^2 + \left(\frac{2y}{w_rbc}\right)^2 = 1 \quad \text{(2.10)}
\]

where,

\[
y = \frac{w_rbc}{2} - \frac{w_s}{2} + 6
\]

\[
z = \frac{hr_{bc}}{2} - hf
\]

Substituting equation 2.9 and solving for \(h\) results in:

\[
h = \left\{ \frac{r_{bc} - \frac{r_{bc}}{2}}{2} \sqrt{\frac{w_s - 12}{w_c r_{bc}}} - \frac{w_s - 12}{w_c r_{bc}} \right\} \left[ \frac{1 + \frac{r_{bc}}{2} + \frac{r_{bc}}{2} \sqrt{\frac{w_s - 12}{w_c r_{bc}}} - \frac{w_s - 12}{w_c r_{bc}}}{2} \right] + 1 \quad \text{h_c} \quad \text{(2.11)}
\]

Table 2.9, presents inside cabin widths and inner fuselage height for each comfort level and seating configuration. In Table 2.9 round-off radii of \(r_{bc} = .2, .5, .8, \) and 1.0 are used. From Table 2.9 it is apparent that for large round-off radii, \(r_{bc}\), the minimum inside body height, \(h_b\), required to meet comfort level constraints can become overly large. Therefore it would seem that if cabin wetted area is to be minimized, a smaller \(r_{bc}\) would be preferable.

To check that adequate room for a passenger is indeed provided, the minimum comfort level 1/1 seating configuration was again used. Figure 2.21 provides the resulting cabin cross-sections for upper round-off radii values of \(r_{tc} = .2, .5, .8, \) and 1.0. In all cases the lower round-off radius is \(r_{bc} = 0.2\). Note that this gives very
NOTE:
Minimum Comfort Level Dimensions

Figure 2.21 Minimum Cabin Dimensions
<table>
<thead>
<tr>
<th>Comfort Level (Table 2.3)</th>
<th>Seat Config.</th>
<th>Cabin Width, $w_c$ (in.)</th>
<th>Inside Body Height, $h_b$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$r_{bc} = .2$</td>
<td>$r_{bc} = .5$</td>
</tr>
<tr>
<td>Minimum</td>
<td>1/1</td>
<td>48</td>
<td>64.6</td>
</tr>
<tr>
<td>Minimum</td>
<td>1/2</td>
<td>66</td>
<td>65.3</td>
</tr>
<tr>
<td>Minimum</td>
<td>2/2</td>
<td>84</td>
<td>65.8</td>
</tr>
<tr>
<td>Adequate</td>
<td>1/1</td>
<td>58</td>
<td>70.4</td>
</tr>
<tr>
<td>Adequate</td>
<td>1/2</td>
<td>78</td>
<td>71.1</td>
</tr>
<tr>
<td>Adequate</td>
<td>2/2</td>
<td>98</td>
<td>71.7</td>
</tr>
<tr>
<td>Maximum</td>
<td>1/1</td>
<td>64</td>
<td>76.2</td>
</tr>
<tr>
<td>Maximum</td>
<td>1/2</td>
<td>86</td>
<td>76.9</td>
</tr>
<tr>
<td>Maximum</td>
<td>2/2</td>
<td>108</td>
<td>77.5</td>
</tr>
</tbody>
</table>
reasonable results for \( r_{tc} \leq 0.8 \). Although other examples are not presented here for the sake of brevity, in general it was found that for \( r_{tc} \leq 0.8 \) all seated headroom constraints could be met.

It should be noted again that this method sizes the inside cross-section only for the minimum dimensions, given the comfort level constraints. It might be desirable, for instance, to increase the under-the-floor height to allow for baggage, wing carry-through structure or landing gear retraction. These considerations are not inherently taken into account by this method.

Methods have been discussed to size both circular and rounded-rectangular cross-sections. It was found that all of the circular cross-section methods provided results which were reasonable for configurations with three and four seats abreast, but that appeared to be either too small (GASP) or too large (Boeing and Douglas) for configurations with only two seats abreast. Of these methods only the GASP method did not directly account for adequate clearances for a seated passenger. Of the other two methods the McDonnell Douglas method seemed to provide the best results for the two-seats-abreast case. Also the McDonnell Douglas method is slightly easier to check and to alter should different seat sizes be chosen. For these reasons it was decided to adopt the McDonnell Douglas method to incorporate into GASP for circular sections. The rounded-rectangular method also appears to provide reasonable results, and in this case, particularly for the smaller seating configurations. This method has the distinct advantage of providing a way of sizing short haul aircraft for cargo payloads, also. The round-off radii may be input as desired, although it was found that for round-off radii greater than 0.8 a circular sizing method would be preferable. Therefore this method will also be used to provide added versatility to the cabin sizing process.

Up until this point only the inner cabin dimensions have been dealt with. Only one method was found to account for structure,
upholstery, etc., in general. The Boeing method determined the inside
ca\bin diameter to be 94% of the outside diameter. Although this is
somewhat conservative for smaller unpressurized airplanes, this method
will be used to determine the outside dimensions.

2.1.2 Determination of Cabin Length

At this point the cabin length will be determined only as that
length required for passenger seating. It will be assumed that for
short haul/commuter airplanes of size and range being considered that
cabin attendants and lavatory facilities will not be necessary.
Baggage compartment requirements will be considered in Section 2.4.

To determine the cabin length for passenger seating equation
2.12 will be used:

\[ L_{\text{PAX}} = N_{\text{ROWS}} \times l_s \]  \hspace{1cm} (2.12)

where,

\[ N_{\text{ROWS}} \] = number of rows of seats

\[ l_s \] = seat pitch in inches.

2.2 Nose Cone Configuration

The primary consideration in designing the nose cone and wind-
shield geometry is the cockpit arrangement and visibility. The cockpit
constraints must be met if the crew are to be able to fly the airplane.
Other considerations however include the drag increment resulting from
the windshield, nose gear retraction, and some stability characteristics.
The main emphasis in this section will be placed upon the design of the
nose for adequate cockpit volume and visibility.

The GASP default* size for the cockpit has a flight deck 4.44 ft.
long. Based on the data available in References 9 and 10 this
might prove inadequate. Figure 2.22 presents the recommended

*Note: A "default" quantity is a value stored in the computer
routine which is used as the value of a particular
variable when no value is input by the user.
Figure 2.22 Recommended Flight Deck Dimensions
For Transport Aircraft
(Reproduced from Reference 9)
dimensions for the flight deck. Based on these dimensions it was decided to design a standardized "crewbox" about which the nose might be shaped. The nose is to be modelled by superimposing two elliptical cones as shown in Figure 2.23. The crewbox will be located on the front of the cabin as shown in Figure 2.24. The shorter of the two cones, or cockpit shell will then be sized for the flight deck.

Figure 2.23 Superimposing of Two Elliptical Cones to Define Nose Cone/Windshield Geometry

Figure 2.24 Location of the Crewbox
Using the dimensions of Figure 2.22 it was possible to define a more or less standard shape for the crewbox. The dimensions for this crewbox are presented in Figure 2.25. Note from Figure 2.25 that the width of the crewbox is defined as in equation 2.13. The minimum distance between crew seat center lines for the class of aircraft in question should be about thirty inches, according to Reference 9. Also it is assumed that, as a minimum, the crew seats are of the same width as the passenger seats.

\[
w_{cb} = w_s + 30 \text{ (inches)}
\]  

(2.13)

The length of the nose shell, i.e. the long thin cone of Figure 2.23 is difficult to specify in any generalized form. It was found that the best method is to specify the ratio of the lengths of the two cones. In choosing a length ratio certain factors should be kept in mind. Some of these are:

- Forward and downward visibility on approach
- Nose gear location and retraction method
- Possible installation of radar
- Desirability of a nose baggage compartment
- Longitudinal and directional static stability.

Although attempts were made to develop a method to size the nose shell based on these factors no successful method was derived. Instead, the length ratio approach seems to provide adequate results. It was found that for commuter aircraft the length ratio was normally between 1.5 and 2.5.

2.3 Tail Cone/Empennage Configuration

In line with the objective of minimizing the fuselage/empennage drag and weight while maintaining stability constraints, the Roskam/Fillman method was chosen to be used to size the tail cone and empennage. The Roskam/Fillman method as originally published in Reference 11 represented an approach to optimizing fuselage and
Figure 2.25 Crewbox Dimensions

NOTE:
1) Based on Figure 2.21
2) Crewbox Width
   (Crew of 2)
   $W_{cb} = W_s + 30$
empennage size with respect to zero-lift drag while maintaining certain stability and control characteristics. The zero-lift drag of the fuselage is a direct function of the fuselage fineness ratio, \( \frac{L_B}{D} \). If it is assumed that the size and shape of the aircraft nose and cabin are dictated by the utility constraints then the fineness ratio may be varied by altering the 'tail cone' length, \( L_c \).

If certain stability and control characteristics are specified as constants, then the optimization process becomes a trade-off between fuselage and empennage drag. Fuselage zero-lift drag may be approximated by equation 2.14 (from Reference 12).

\[
C_{D_{0\text{B}}} = C_f \frac{1 + \frac{60}{(L_B/D)^3} + 0.0025 \frac{L_B}{D} \frac{(SW_{\text{body}})}{SW_{\text{wing}}}}{SW_{\text{wing}}}
\] (2.14)

The zero-lift drag of either the vertical or horizontal tail may be estimated by equation 2.15 (from Reference 12).

\[
C_{D_{0\text{VorH}}} = C_f [1 + \frac{L(t/c)}{SW_{\text{VorH}}} + 100(t/c)^4] \frac{SW_{\text{VorH}}}{SW_{\text{wing}}}
\] (2.15)

As the fineness ratio, \( \frac{L_B}{D} \), is increased by lengthening the tail cone the following occur:

- Increasing \( \frac{L_B}{D} \) will increase the fuselage Reynolds number decreasing \( C_f \).
- Increasing \( \frac{L_B}{D} \) will decrease the value in the brackets of equation (2.14).
- Increasing \( \frac{L_B}{D} \) will increase \( SW_{\text{Body}} \).
- Increasing \( \frac{L_B}{D} \) will reduce the empennage wetted area requirements, for constant stability levels.

One simplifying assumption made in the method as originally published in Reference 11 was that the aircraft aerodynamic center location could be considered as a constant as the tail cone was lengthened. The overall intent was to trade off a reduction in empennage drag for an increase in fuselage drag in hopes of finding...
the minimum drag configuration.

To use the Roskam/Fillman method to size the fuselage and empennage for minimum weight and drag a number of changes became necessary. Weight estimation of the fuselage and empennage was added as well as a c.g. location method. With these additions static stability constraints could be specified as a constant $C_{n\alpha}$ for the longitudinal case and a constant $C_{n\beta}$ for the directional case. As with the original method, it was assumed that the airplane geometry forward of the tail cone would remain unchanged.

To test the method a computer program was written in FORTRAN IV to facilitate the method's application to both existing and conceptual aircraft. This section will describe the program methods and discuss the results it produced.

2.3.1 Roskam/Fillman Program Description

A flowchart of the program is presented in Figure 2.26. A program listing and an explanation of how the input data are prepared are presented in Appendix B of this report. Explanations of the methods used in each of the main subroutines are provided in the following paragraphs. Note that on Figure 2.26 Section numbers refer to the section in which a discussion of each method is presented.

2.3.1.1 Computation of Wetted Areas

The wetted areas for the fuselage and empennage are computed in the following manner in the subroutine SWET.

The fuselage wetted area is computed in three components: the cabin wetted area, the nose wetted area, and the tail cone wetted area. The cabin is assumed to be a right circular cylinder. The cabin wetted area is expressed as in equation 2.16.

$$S_{\text{Wet Cabin}} = \pi D L_u$$  \hspace{1cm} (2.16)
INPUT:
AIRCRAFT GEOMETRY
FLIGHT CONDITIONS
STABILITY CONSTRAINTS
'Cm' AND 'Cp'
RANGE OF TAIL CONE
VARIATIONS

ANALYZE BASE CONFIG:
1. COMPUTE WETTED AREAS (SECT. 2.3.1.1)
2. COMPUTE CDP (SECT. 2.3.1.2)
3. COMPUTE FUSELAGE AND EMPENNAGE WEIGHT (SECT. 2.3.1.3)
4. LOCATE C.G. (SECT. 2.3.1.4)

ANALYZE NEW CONFIG:
1. COMPUTE WETTED AREAS (SECT. 2.3.1.1)
2. COMPUTE FUSELAGE WEIGHT (SECT. 2.3.1.3)
3. COMPUTE EMPENNAGE WEIGHT (SECT. 2.3.1.3) BASED ON LAST SIZING
4. LOCATED NEW C.G. (SECT. 2.3.1.4)
5. SIZE EMPENNAGE BASED ON STABILITY CONSTRAINTS (SECT. 2.3.1.5)
6. RECOMPUTE WETTED AREAS (SECT. 2.3.1.1)
7. COMPUTE (Cv) (SECT. 2.3.1.2)

OUTPUT:
1. BASE CONFIG. DATA:
   • FLIGHT CONDITIONS
   • AIRCRAFT GEOMETRY
   • WEIGHT & BALANCE
   • WETTED AREAS
2. DATA VS. TAIL CONE LENGTH:
   • WEIGHT & BALANCE
   • STABILIZER SIZE
   • VERT. TAIL SIZE
   • A.C. LOCATIONS
   • WETTED AREAS

Figure 2.26 Flowchart of Roskam/Fillman Method Program
The wetted areas of the nose cone and tail cone are computed using Torenbeek's elliptical cone methods of Reference 9. This approach is documented in Appendix A of this report. By using Figures A-1 and A-3 of Appendix A to determine the shape parameters, $\phi$, for the nose and tail cones, it is possible to determine a wetted area correction factor, $k_w$, from Figure A-2 of Appendix A. The wetted areas for the nose and tail may then be expressed as in equations 2.17 and 2.18:

\[
\text{(S\text{WET})_{\text{NOSE}}} = (k_w)_{\text{NOSE}} w_N
\]  

\[
\text{(S\text{WET})_{\text{TAIL}}} = (k_w)_{\text{TAIL}} w_c
\]  

The wetted area of the fuselage is then expressed as:

\[
\text{(S\text{WET})_B} = \text{(S\text{WET})_{\text{CABIN}}} + \text{(S\text{WET})_{\text{NOSE}}} + \text{(S\text{WET})_{\text{TAIL}}}
\]  

The horizontal and vertical tail wetted areas were computed with the aid of a surface area correction factor, $K_p$, from Corning (Reference 13). This surface area correction factor is a function of the airfoil thickness ratio, $t/c$, as shown in Figure 2.27.

![Figure 2.27 Determination of the Surface Area Correction Factor, $K_p$ (Reproduced from Reference 13)](image-url)
Using Figure 2.27 the wetted areas of the horizontal and vertical tails may be determined as:

\[ S_{\text{WET}}^{H \text{ or } V} = K_p (S)^{H \text{ or } V} \]  \hspace{1cm} (2.20)

Where,

\[ K_p = 0.52 \left( \frac{E}{c} \right) + 1.987 \]

2.3.1.2 Calculation of Zero-Lift Fuselage/Empennage Drag

The zero-lift drag of the fuselage and empennage are computed in the subroutine CDO using equations 2.14 and 2.15 as stated earlier.

\[
\begin{align*}
(C_D^o)_{\text{B}} &= C_f \left[ 1 + \frac{60}{(L_B/D)^3} + 0.0025 \frac{L_B}{D} \right] \left( \frac{S_{\text{WET}}^{\text{BODY}}}{S_{\text{WING}}} \right) \\
(C_D^o)_{V \text{ or } H} &= C_f \left[ 1 + L \frac{f}{c} + 100 \left( \frac{f}{c} \right)^4 \right] R_{L,S} \left( \frac{S_{\text{WET}}^{V \text{ or } H}}{S_{\text{WING}}} \right) 
\end{align*}
\]  \hspace{1cm} (2.14) and (2.15)

The mean skin-friction coefficients, \( C_f \), are a function of Reynolds number, \( R_N \), and Mach as shown in Figure 2.28. The factors \( L \) and \( R_{L,S} \) are as defined in Reference 11.

2.3.1.3 Calculation of Fuselage and Empennage Weight

The structural weights of the fuselage and empennage are mainly dependent on their areas and the maximum speed of the aircraft. The following equations were taken from Reference 9. The equation for fuselage shell weight estimation is:

\[
W_F = k_{WF} \sqrt{V_D b_f + h_f} \left( S_C \right)^{1.2} \cdot K_1 \cdot K_2 \cdot K_3 \cdot K_4 \]  \hspace{1cm} (2.21)
Figure 2.28 Turbulent Mean Skin-Friction Coefficient on an Isolated Flat Plate
Figure 2.28 Turbulent Mean Skin-Friction Coefficient on an Isolated Flat Plate

2.46
Where \( k_{WF} = 0.021 \) for \( W_F \) in LBS

\[ W_F = \text{Fuselage Weight (lbs)} \]

\[ V_D = \text{Design dive speed (kts)} \]

\[ S_G = \text{Gross shell area (ft}^2\text{)} \]

\[ b_f = \text{Maximum fuselage width (ft.)} \]

\[ h_f = \text{Maximum fuselage height (ft.)} \]

\[ L_h = \text{Distance from wing quarter chord to horizontal tail quarter chord (ft.)} \]

\[ K_1 = 1.00 \text{ for unpressurized fuselage} \]

\[ = 1.08 \text{ for pressurized fuselage} \]

\[ K_2 = 1.00 \text{ for wing mounted engines} \]

\[ = 1.04 \text{ for fuselage mounted engines} \]

\[ K_3 = 1.00 \text{ for main gear attached to wing} \]

\[ = 1.07 \text{ for main gear attached to fuselage} \]

\[ K_4 = 1.00 \text{ for main gear bay in the fuselage} \]

\[ = 0.98 \text{ for no main gear bay in the fuselage} \]

As can be seen from equation 2.21, the weight is dependent on the square root of the dive speed and the wetted area to the 1.2 power!

The empennage weight is dependent on the load factor and the square of the wetted area for dive speeds less than or equal to 250 kts.

\[
W_{EMP} = K_{WT} \left[ \eta_{ULT} \cdot \frac{S_{EMP}^2}{S_{EMP}} \right]^{0.75}
\]

(2.22)

where \( K_{WT} = 0.04 \) for \( V_D \) in KTS

\[ W_{EMP} \text{ in LBS} \]

\[ S_{EMP} \text{ in FT}^2 \]

\[ \eta_{ULT} = \text{Ultimate airplane load factor} \]

\[ S_{EMP} = \text{Empennage Planform area} \]

2.47
For dive speeds greater than 250 kts. the empennage weight is a direct function of the planform area and the terms $F_H$ and $F_V$ which are defined below.

$$W_{HT} = K_H \cdot S_H \cdot f(F_H) \quad (2.23)$$

$$W_{VT} = K_V \cdot S_V \cdot f(F_V) \quad (2.24)$$

where $V_D$ = Dive speed in kts.

- $S_H$ = Horizontal Tail Planform area
- $S_V$ = Vertical Tail Planform area
- $K_H$ = 1.0 for fixed stabilizer
  - = 1.1 for variable incidence stabilizer
- $K_V$ = 1.0 for fuselage mounted horizontal tails
  - = 1.0 + .15 $\frac{S_H b_H}{S_V b_V}$ for T-Tails

where $b_H$ = Height of Horizontal Tail above Fin Root

$\quad b_V$ = Vertical Tail span

$$F_H = \frac{V_D \left(S_H\right)^{1.2}}{1000 \sqrt{\cos \Lambda_H}} \quad (2.25)$$

$$F_V = \frac{V_D \left(S_V\right)^{1.2}}{1000 \sqrt{\cos \Lambda_V}} \quad (2.26)$$

where $\Lambda$ = sweep in degrees at the maximum airfoil thickness

The values of the parameters dependent on $F_H$ and $F_V$ can be determined from Figure 2.29. These equations were programmed and are used to calculate the shell weights used in the Roskam/Fillman program in the subroutines FUSWGT and EMPWGT.
One of the input parameters for the Roskam/Fillman program is the baseline airplane's gross weight. Using this gross weight and the baseline shell weights of the fuselage and empennage, it is possible to correct for change in gross weight due to the change in tail cone and empennage configuration. This is done in the following manner. Equation 2.21 shows that the fuselage weight is proportional to fuselage gross wetted area to the power 1.2. It is assumed that to approximate the shell weight of the tail cone equation 2.27 may be applied.

\[
W_{TAIL} = \frac{(S_{WET})_{TAIL}}{(S_{WET})_{BODY}} W_F \tag{2.27}
\]

This weight and the weight of the empennage are then subtracted from the baseline gross weight to provide an adjusted gross weight, \(W_{GR}'\). It is then assumed that \(W_{GR}'\) remains constant and that only the tail cone and empennage weights vary.

2.3.1.4 Location of the Center of Gravity

The longitudinal c.g. location is required to size the empennage for stability constraints. The c.g. location subroutine, SBARCG, performs this function. The routine is not intended to locate the c.g. accurately, but rather to estimate the shift in c.g. location due to incrementally lengthening the tail cone. The equation used to locate the c.g. was as expressed in equation 2.28.
where, $W_{GR}$ = adjusted gross weight (lbs) (See Section 2.3.1.3)  
$(X_{cg})_o$ = baseline c.g. location relative to the nose (ft.)  
$W_{TAIL}$ = tail cone shell weight (lbs)  
$(X_{cg})_{TAIL}$ = tail cone c.g. location relative to the nose (ft.)  
$W_H$ = horizontal tail weight (lbs)  
$(X_{cg})_H$ = horizontal tail c.g. location relative to the nose (ft.)  
$W_V$ = vertical tail weight (lbs)  
$(X_{cg})_V$ = vertical tail c.g. location relative to the nose (ft.)  
$W_{GROSS}$ = total gross weight for i'th tail cone/empennage configuration (lbs)  
$\varepsilon_{cg}$ = c.g. correction found as the difference between estimated c.g. location for baseline and actual c.g. location for the baseline.

The tail cone c.g. location $X_{cg}$ TAIL was located at the centroid of a body of revolution having a planform shape modelled by the equation:

$$
\left(\frac{x}{a}\right)^n + \left(\frac{y}{b}\right)^m = 1
$$

(2.29)

With a cone shape of this type, it may be shown that the centroid of the tail is located by equation 2.30.
\[
\bar{x}_{TAIL} = \frac{1}{2} - \frac{1}{m(n + 2)} + \frac{1 - m}{4m^2(2n + 2)} - \frac{1 - 3m + 2m^2}{6m^2(3n + 2)} \bar{Z}_c
\]

Therefore, the c.g. of the tail, relative to the nose is located as:

\[
X_{cg TAIL} = \bar{Z}_N + \bar{Z}_u + \bar{x}_{TAIL}
\]  (2.31)

The baseline c.g. locations for the horizontal and vertical tails were input parameters, although for preparation of the data, where more accurate data were lacking, it was assumed that the c.g. was at 60% of the mean geometric chord, . To correct for tail cone length changes equation 2.32 was used.

\[
\left( X_{cg} \right)_{H or V} = X_{cg o H or V} + \Delta \bar{L}_c
\]

where,

\[X_{cg o} = \text{baseline c.g. location relative to the nose (ft.)}\]

\[\Delta \bar{L}_c = \text{change in tail cone length relative to the baseline (ft.)}\]

As stated before, this routine was intended to provide only quick and dirty estimations for c.g. location based on the limited input parameters that the program used. It was anticipated that if the method had been integrated into the GASP, that the GASP c.g. location method would provide better results.

2.3.1.5 Empennage Sizing

The horizontal and vertical tails were to be sized to meet specified static stability constraints. The horizontal tail was to be sized to provide a specific \[C_{m o}\] value, and the vertical tail a
specific $C_m$ value. In addition to this, it was decided to optimize the effectiveness of the horizontal and vertical tails for each tail cone length. These functions were performed for the horizontal and vertical tails in the subroutines STABAREA and VERTAREA respectively.

The effectiveness of each surface was to be optimized by maximizing the product of the lift curve and moment arm for each surface. The variable was to be the sweep of the surface. For instance, by varying the sweep of the horizontal tail, both the horizontal tail moment arm, $l_h$, and the horizontal tail lift curve slope, $C_{L_{\alpha_H}}$, are affected. The tail may be said to be most effective where the product $C_{L_{\alpha_H}} \times l_h$ is a maximum. The value of $l_h$ is easily defined geometrically, and the value of $C_{L_{\alpha_H}}$, from Reference 14, may be expressed as:

$$C_{L_{\alpha}} = \frac{2\pi A}{2 + \sqrt{(\frac{\Delta A}{\kappa})^2 \left(1 + \frac{\tan^2 \Lambda_c/2}{\beta^2}\right) + 4}}$$

(2.33)

where,
- $A$ = aspect ratio
- $\beta$ = Prandtl-Glauert transformation, $\sqrt{1 - M^2}$
- $\kappa$ = ratio of the actual section lift curve slope to $2\pi$
- $\Lambda_c/2$ = half-chord sweep

The program assumes that the aspect ratios of the horizontal and vertical tails remain constant, allowing this procedure to be more or less independent of the sizing.

The horizontal tail is to be sized for a constant $C_{m_{\alpha}}$ value.

From Reference 14:

$$C_{m_{\alpha}} = \left(\bar{x}_{cg} - \bar{x}_{ac}\right) C_{L_{\alpha}}$$

(2.34)
where all of the above values are total aircraft values.

From Reference 14:

\[
\tilde{X}_{ac} = \left( \bar{X}_{ac} \right)_{WB} + \frac{C_{L_d H}}{C_{L_d WB}} \eta_H \frac{S_H}{S} \bar{X}_{ac H} \left( 1 - \frac{de}{d\alpha} \right) \]

\[
1 + \frac{C_{L_d H}}{C_{L_d WB}} \eta_H \frac{S_H}{S} \left( 1 - \frac{de}{d\alpha} \right) \]

Solving for \( S_H \) renders:

\[
S_H = \frac{\left( \tilde{X}_{ac WB} - \tilde{X}_{ac} \right) S}{\left( \tilde{X}_{ac} - \tilde{X}_{ac H} \right) \frac{C_{L_d H}}{C_{L_d WB}} \eta_H \left( 1 - \frac{de}{d\alpha} \right)} \]

(2.36)

All of the variables on the right-hand side of equation 2.36 are determined using the methods of Reference 14. In particular, however, the \( \tilde{X}_{ac WB} \) is determined as:

\[
\tilde{X}_{ac WB} = \tilde{X}_{ac W} + \Delta \tilde{X}_{ac B} \]

(2.37)

Whereas the \( \tilde{X}_{ac} \) of the wing, \( \tilde{X}_{ac W} \), is an input parameter, the aerodynamic center shift due to the body, \( \Delta \tilde{X}_{ac B} \), is computed by performing a Multhopp strip-integration as described in Reference 14. This is accomplished in the subroutine MULTOP.

The total aircraft lift slope in equation 2.34 may be expressed as:

\[
C_{L_d} = C_{L_d WB} + C_{L_d H} \eta_H \frac{S_H}{S} \left( 1 - \frac{de}{d\alpha} \right) \]

(2.38)
The program uses equations 2.36 and 2.38 to iterate to find a value for $S_H$ which will meet the $C_{m\alpha}$ constraint.

The vertical tail size is determined in a similar manner. From Reference 14, the value for the $C_{n\beta}$ of the aircraft may be expressed as:

$$C_{n\beta} = C_{n\beta_B} + C_{n\beta_W} + C_{n\beta_V} \quad (2.39)$$

where,

- $C_{n\beta_B}$ = the body contribution to $C_{n\beta}$ (rad$^{-1}$)
- $C_{n\beta_W}$ = the wing contribution to $C_{n\beta}$ (rad$^{-1}$)
- $C_{n\beta_V}$ = the vertical tail contribution to $C_{n\beta}$ (rad$^{-1}$)

It is conservative to assume that the wing contribution is negligible. Therefore, equation 2.39 becomes:

$$C_{n\beta} = C_{n\beta_B} + C_{n\beta_V} \quad (2.40)$$

or,

$$C_{n\beta_V} = C_{n\beta} - C_{n\beta_B} \quad (2.41)$$

From Reference 14 the body contribution may be determined as:

$$C_{n\beta_B} = \frac{-57.3}{N} K R_{L} \frac{S_B}{S} \frac{g_B}{b} \quad (rad^{-1}) \quad (2.42)$$

where,

- $K_N$ = an empirical factor for body and body + wing effects determined from Figure 7.19 of Reference 14.
- $K_R_L$ = a Reynolds's number factor for the fuselage determined from Figure 7.20 of Reference 14.
- $S_B = $ body side area (ft$^2$)
- $S = $
- $g_B = $ body length (ft)

2.54
The side body area is computed using the methods of Appendix A of this report.

The vertical tail contribution, $C_{n_{\beta V}}$, may be expressed as shown in equation 2.42 (Reference 14).

$$C_{n_{\beta V}} = -C_{y_{\beta V}} \left( \frac{z_V \cos \alpha + z_S \sin \alpha}{b} \right) \text{ (rad}^{-1})$$ (2.42)

For an airplane in the cruise configuration it is reasonable to assume that the angle of attack is small. Therefore:

$$C_{n_{\beta V}} = -C_{y_{\beta V}} \frac{z_V}{b}$$ (2.43)

From Reference 14:

$$C_{y_{\beta V}} = -k C_{L_{\alpha V}} \left( 1 + \frac{d \alpha}{d \theta} \right) \eta \frac{S_V}{S} \text{ (rad}^{-1})$$ (2.44)

where,

$k = \text{an empirical factor from Figure 7.3 of Reference 14.}$

$C_{L_{\alpha V}} = \text{the vertical tail lift curve slope determined from equation 2.33 using } A = A_{\text{eff}.}$ The value of the effective aspect ratio, $A_{\text{eff},}$ is determined by the methods of Reference 14.

The value of the factor $1 + \frac{d \alpha}{d \theta} \eta$ is assumed to be approximately 1.0.

Substitution and solving equation 2.40 for $S_V$ renders:

$$S_V = \frac{S_{b \beta} C_{n_{\beta}} + 57.3 N K_{\beta} \frac{K_{\beta}}{S_{b \beta}} S_{b \beta}}{k C_{L_{\alpha V}} Z_V} \text{ (ft}^2)$$ (2.45)

By iterating between the equation for $C_{L_{\alpha V}}$ and equation 2.45, the value for $S_V$ which meets the $C_{n_{\beta}}$ constraint may be determined.

2.55
2.3.2 Results of the Roskam/Fillman Program

The Roskam/Fillman method was tested using data for both actual and conceptual baseline aircraft. Although preliminary results for the Gates-Learjet Model 24 seemed to verify the method, later results for both other existing aircraft, and for the conceptual aircraft in particular, were rather disappointing. For the sake of brevity only a generalized discussion of the results and the conclusions based thereon will be presented here. A more detailed discussion of the airplane configurations tested and the results is presented in Reference 15.

When the tests were made, as was expected the vertical tail size required to maintain $\eta_\alpha$ decreased with increasing tail cone length. On the other hand, with many of the aircraft tested, as the tail cone length was increased so did the horizontal tail size required to maintain $\eta_\alpha$. This was not as expected. As a result the increasing drag and weight of the horizontal tail and tail cone together over-rode the decreasing drag and weight of the vertical tail.

After carefully evaluating the Roskam/Fillman algorithm the following conclusions as to the cause of the difficulties were arrived at. The method assumes that the wing may be kept at a constant location relative to the nose of the aircraft. Because of this and the fact that the aft portion of the fuselage has very little effect on the shift in aerodynamic center due to the body, the location of the wing+body aerodynamic center remains relatively constant. As the tail cone is lengthened the aircraft c.g. moves aft. It is probable that inherent inaccuracies in the "quick-and-dirty" method used to locate the c.g. pushed it even farther aft than should have been the case. It is also reasonable to assume that the lift slope of the total aircraft is not going to change drastically with changes in tail cone and horizontal tail size. Therefore by referring to equation 2.34 note that

2.56
as the c.g. is pulled aft by the tail cone, the aircraft aero-
dynamic center is also pushed aft to maintain the static margin.
Realizing this and the fact that the wing + body aerodynamic
center is more or less fixed, note that the numerator of equation
2.36 is going to become considerably larger. At the same time,
the \( \left( \bar{X}_{ac} - \bar{X}_{ac_H} \right) \) factor in the denominator may also be decreasing,
compounding the effect.

The program was written so that some of the computations
made for each tail cone increment relied on some of the data from
the previous tail cone increment. This was done to reduce the
number of iterative cycles required. In particular, to locate
the c.g. at a new tail cone length, the empennage sizes from
the previous tail cone length were used. This was originally
felt to be reasonable as long as the increments in tail cone
length were small. Unfortunately, this also resulted in pushing
the c.g. even farther aft in light of the oversized horizontal
tail. Thus the problem was doubly compounded.

From this evaluation of the algorithm employed the following
conclusions and recommendation as to the usefulness of the method
may be made:

Before the method may be applied reliably to determine if
an optimum tail cone length (from a weight and drag viewpoint)
may be found:

A) An accurate c.g. location routine is needed. Also
   if this is to be done, it would be wise to include
   a more accurate estimation of the component weights
   and how they might be altered by changing tail cone
   length.

B) The re-balancing of the wing on the fuselage for each
new tail cone cone configuration might be investigated
   to prevent the distance between the wing + body aero-
dynamic center and the total aircraft aerodynamic center
   from becoming overly large. One disadvantage to the
re-balancing of the wing would be to reduce the effect of an increased horizontal tail moment arm, with the possible result that the overall objective of the method is cancelled.

C) The algorithm needs to be revised such that the calculations for each new configuration are independent of all previous configuration data. This would reduce the probability of compounding errors.

The most obvious means of accomplishing these revisions was to include the empennage sizing subroutines into the GASP and then to change the tail cone lengths by external manipulations. This would also allow checking the method both with and without re-balancing the wing. Work was being accomplished to this end before the writing of this report but, due to the difficulties encountered in trying to put the GASP into an operational status, could not be completed.

The technical monitor of this project at NASA-Ames, Tom Galloway, performed some preliminary calculations using the GASP to test the method's application. The empennage sizing method in this case was the \( \bar{V} \) method currently used by the GASP. The results from Tom Galloway's study (Reference 16) indicate that the increasing weight of the tail cone structure with increasing length will more than overcome the decreasing weight of the empennage. Drag, on the other hand, did decrease as expected. The intent of this procedure, it must be remembered, was to minimize DOC. However, DOC is much more dependent upon weight than drag. Consequently, Tom Galloway's results indicate that a shorter tail cone is better from a DOC point of view. Nevertheless, we believe that by revising the GASP in the manner suggested above to implement the Roskam/Fillman method, studies in this area might prove beneficial.

2.4 Baggage Compartment Study

It is necessary to allow enough room for passenger baggage. Since the shorthaul/commuter airplane is frequently used to
Figure 2.30 Baggage Dimensions

Table 2.10 Baggage Allowance

<table>
<thead>
<tr>
<th>Baggage Type</th>
<th>x Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Suitcase</td>
<td>62 inches</td>
</tr>
<tr>
<td>Small Suitcase</td>
<td>55 inches</td>
</tr>
<tr>
<td>Total Weight</td>
<td>70 pounds</td>
</tr>
</tbody>
</table>

where $x = \ell + h + w$
transport passengers to the major airlines, it is desirable to allow for the same amount of baggage as the major airlines specify.

The problem of storage location was investigated in Reference 15, and three storage methods were studied, two of which were cabin oriented and the other, tail cone oriented. For the cabin-oriented storage methods the limitation was availability of required volume. For the tail-cone storage method the critical consideration was c.g. location.

To establish the baggage allowances for shorthaul/commuter airplanes, several major carriers were questioned about their baggage allowances. It was discovered that most major carriers specify baggage allowance by the sum of the baggage dimensions and total weight rather than by volume. The major carriers allow two pieces of checked luggage plus one carry-on piece. These baggage allowances are summarized in Table 2.10. Figure 2.30 defines the baggage dimensions. One major airline allows 5.0 cu. ft. per passenger for its Trijet service.

To attempt to determine a volume corresponding to the allowances of Table 2.10 a survey of baggage dimensions was performed using the catalog of a major retail chain. From the survey the dimensions listed in Table 2.11 were selected as representative. The original baggage compartment study documented in Reference 15 used the baggage volume indicated by Table 2.11. In that study the required baggage compartment volumes for 12, 21, and 30 passenger configurations were computed. It was assumed that no additional allowances were needed for carry-on baggage, as this baggage may be stored under the passengers' seats.

<table>
<thead>
<tr>
<th>Table 2.11 Representative Baggage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>L</strong></td>
</tr>
<tr>
<td>Large Suitcase</td>
</tr>
<tr>
<td>Small Suitcase</td>
</tr>
<tr>
<td>Total Volume</td>
</tr>
</tbody>
</table>
\((\Delta L_u) \text{ BAGGAGE} = 4.566 \text{ ft}\)

The result, although slightly small, looks reasonable. This method will be used to size for the baggage compartment.

2.5 **Fuselage Shape Simulation Program, FUSE**

A computer program was written to simulate and design commuter aircraft fuselages. The purpose of this program was two-fold. First, the program was intended to provide a method for modelling actual aircraft fuselages to provide node coordinates for use with finite element analysis procedures. This modelling method was to be simple to apply and versatile enough to be used with most commuter aircraft slopes. The second purpose of the program was to provide a means for applying and evaluation the design methods previously discussed in this chapter. In addition to these objectives for the program, an option was included to allow for interactive graphic display of the resulting design or simulation to ensure reasonable configurations. The final version of the program at the time of this report is intended to be used with a Tektronix 4014 or 4015 graphic display terminal using the PLOT 10 graphics software package (Reference 18). The computer program, which will be referred to as FUSE, was written in FORTRAN IV for a Honeywell 56/60 timesharing system. Appendix C of this report contains a complete listing and user's guide for the program.

The program was originally documented in Reference 19. At that time the program was only used in batch operations for actual aircraft simulations and plotting of the simulated fuselages was performed on a Benson Lehner plotter. Although the design mode and the interactive graphics have been added the modelling routines are essentially the same. Section 2.5.1 will discuss the approach taken to model the fuselage. Section 2.5.2 will provide the program description. Section 2.5.3 will discuss the program results.
The three methods of baggage storage considered in Reference 15 are shown in Figures 2.30 through 2.33. Reference 17 provides a more detailed analysis of each method. The results of the analysis indicated that only the fuselage lobe baggage compartment could be considered feasible from a volume requirement standpoint. The carry-on baggage compartment would have required that the cabin be lengthened by approximately 50% and the tail cone compartment resulted in center of gravity difficulties. One very important factor was neglected in considering the fuselage lobe compartment, however. No allowance was made in the study for either the wing-carry through structure or the possibility of main landing gear storage. This would be especially critical for the smaller commuter airplanes where the wing root chord is significant in comparison with cabin length.

For these reasons another form of carry-on compartment was considered. Figure 2.31 shows the baggage compartment to be only on one side of the cabin. McDonnell Douglas found in Reference 6 that baggage compartments on either side of the aisle were more efficient from a design-to-cost point of view than the fuselage lobe method. It was decided to try and develop a method to define the length required for this type of baggage compartment. Also, at the suggestion of Tom Galloway, the project technical monitor at NASA-Ames, it was decided to limit the baggage to 5 cu. ft. per passenger.

It was assumed that the baggage compartment could be represented by a trapezoidal cross-section for either the circular or rounded-rectangular cabin sections. It was also assumed that an aisle of 1.5 the normal aisle width would be maintained. The resulting effective baggage compartment cross-sections were to appear as shown in Figure 2.34.

It will be assumed that the aisle-side of the compartment is essentially equal to the inside cabin height, \( h_c \). The base of each side may be represented as in equation 2.46, if McDonnell Douglas control points are used:
Figure 2.31 Carry-on Baggage Compartment

Figure 2.32 Fuselage Lobe Baggage Compartment

Figure 2.33 Tail Cone Baggage Compartment
a) Circular Cabin Section

b) Rounded-Rectangular Cabin Section

Figure 2.34 Definition of Effective Baggage Compartment Area
\[ w_{bc} = \frac{1}{2} \left[ (N_S - 1) w_S - 0.5N_A w_A + 12 \right] \]  

(2.46)

By solving the cross-section equations for a rounded-rectangular section it is possible to find the wall-side compartment height for both circular and rounded rectangular sections as:

\[ h_{bc} = h_c - \frac{h}{2} \left[ 1 - r_{tc} \sqrt{1 - \frac{1}{4} \left( \frac{w_f - w_c + r_{tc} w_c}{r_{tc} w_c} \right)^2} \right] \]  

(2.47)

where,

- \( h \) = inside body height (in.)
- \( w_f \) = floor width (in.) = \((N_S - 1) w_S + N_A w_A + 12\)

Finally, the additional cabin length required to allow for 5 cu. ft. of baggage per passenger may be expressed as:

\[ \Delta L_{\text{BAGGAGE}} = \frac{720 \text{ PAX}}{w_{bc} \left[ 2h_c - \frac{h}{2} (1 - r_{tc}) \sqrt{1 - \frac{1}{4} \left( \frac{w_f - w_c + r_{tc} w_c}{r_{tc} w_c} \right)^2} \right]} \]

where,

- PAX = number of passengers

As a check of the method the baggage compartment length for a 30-passenger cabin of the type presented by McDonnell Douglas in Reference 6 was computed. The actual length was chosen as the average of the lengths of the compartments on either side of the aisle. In this case, that implied an actual baggage compartment length of 5.375 ft.

Given:

- \( w_c = 103 \text{ in.} \)
- \( w_f = 90.5 \text{ in.} \)
- \( w_S = 20 \text{ in.} \)
- \( N_S = 4 \)
- \( w_A = 18.5 \text{ in.} \)
- \( N_A = 1 \)
- \( h = 103 \text{ in.} \)
- \( h_c = 78 \text{ in.} \)
- \( r_{bc} = 1.0 \)
2.5.1 Approach to Fuselage Shape Simulation

For the majority of short haul/commuter aircraft, the fuselage can be considered to be made up of three distinct sections: the nose, the cabin, and the tail cone, as shown in Figure 2.35. This was the basis for the development of FUSE. The intent was to model each of these sections individually and then assemble them. The methods used to model these three fuselage sections will be explained in Sections 2.4.1.3 through 2.5.1.5. As all of the cross-sections will be modelled in the same manner the cross-sections will be discussed in Section 2.5.1.2.

![Figure 2.35 Definition of Generalized Fuselage Sections](image)

2.5.1.1 Coordinate Systems

As FUSE was to be used to provide the nodes for finite-element analysis methods, it was necessary to define a book-keeping system by which the nodes might be located and used. As it was hoped to use FUSE in conjunction with the NCSU BODY program of Reference 20, the node numbering and coordinate system were chosen to be compatible with the BODY program. The coordinate system is such that x is positive aft, y is positive left, and z is positive up. The aircraft is assumed to be symmetric about the
XZ-plane. Therefore, nodes are only simulated for half of the fuselage on the positive-y side.

The fuselage will be subdivided both in the lengthwise direction, and radially about some specified central axis. The nodes will be numbered \((i,j)\) in a coordinate system, where the value of \(i\) represents the number of the corresponding lengthwise subdivision and the value of \(j\) represents the number of the radial segment. For each node, \((i,j)\) values for \(x, y,\) and \(z\) will be computed and stored.

The NCSU BODY program is written so that the number of lengthwise and radial subdivisions are assigned to each fuselage section (nose, cabin, or tail) individually as input parameters. FUSE was written such that the number of lengthwise divisions are input for each section, but that the number of radial divisions is constant for all sections. This facilitates the definition of each panel.

2.5.1.2 Cross-Section Determination, CRSSEC

The original program as documented in Reference 19 assumed that the airplane cross-sections could be modeled by elliptical or circular sections. Also the cross-sections for the nose, cabin and tail cone were determined independently. This sometimes resulted in a discontinuity at the juncture of two fuselage sections. To avoid this problem and to allow for round-rectangular cross-sections, the subroutine CRSSEC was substituted for cross-section calculations.

The approach taken to locating the cross-section nodes is similar to that used in Reference 19. The main difference is that the method has been generalized to account for the use of rounded rectangular cross-sections.

Figure 2.36 will be used to help describe the node location procedure. It will be assumed that the cross-section center is vertically offset from the y-z origin by some value, \(z_0\). The
nodes will be located by rotating a radial line through 180°
(from -90° to +90° relative to the y-axis) from a center point
at $y = 0, z = z_{CL}$. The nodes will be located at the intersection
of the radial and the cross-section shape every $\frac{\pi}{m}$ degrees,
where "$m$" is the number of radial segments desired.

The equation for the radial is as expressed in equation 2.49:

$$z = by + z_{CL} \tag{2.49}$$

where,

$$b = \tan \left( \frac{j - \frac{1}{m}}{\pi} \right) \text{ for } j = 1, 2, 3 \ldots, (m + 1)$$

$m$ = number of radial segments

Note from Figure 2.34 that for $z_{sb} < z < z_{st}$, $y = y_m$. Similarly,
for $b < 0$ and $y < y_{sb}$, $z = z_o - z_m$, and for $b > 0$ and $y < y_{st}$, $z = z_o + z_m$. The values for $y_{st}$, $z_{st}$, $y_{sb}$, and $z_{sb}$ are easily determined by equations 2.50:

\[
y_{st} = y_m (1 - r_t)
\]

\[
z_{st} = z_m (1 - r_t) + z_o
\]

\[
y_{sb} = y_m (1 - r_b)
\]

\[
z_{sb} = z_m (r_b - 1) + z_o
\]

where $r_t$ and $r_b$ are the upper and lower round-off radii expressed as a constant fraction of $y_m$ and $z_m$.

This reduces the node location problem significantly. Only the rounded corners of the section must be dealt with. By solving the cross-section corner equations at either the top or bottom corner it can be shown that:

\[
y = \frac{-3 + \sqrt{B^2 - 4AC}}{2A}
\]

where,

\[
A = 1 + \left(\frac{y_m}{z_m}\right)^2
\]

\[
B = -2y' + 2b \left(z'_{CL} - z'\right)\left(\frac{y_m}{z_m}\right)^2
\]

\[
C = 2y_m y' + \left[\left(\frac{z'_{CL} - z'}{z_m}\right)^2 - 1\right] (y_m)^2
\]

and where,

\[
y' = \begin{cases} y_{st} & \text{for } b > 0 \\ y_{sb} & \text{for } b < 0 \end{cases}
\]

\[
z' = \begin{cases} z_{st} & \text{for } b > 0 \\ z_{sb} & \text{for } b < 0 \end{cases}
\]

With a value for $y$ at any radial position from equation 2.51, the value for $z$ is easily determined from equation 2.49.
An added advantage of the subroutine CRSSEC is that the discontinuities that could occur at the juncture of two fuselage sections may be "faired-out." This has been done at the nose-to-cabin juncture in the following manner. At any nose section radial the node coordinates of both the nose and cabin are determined as if the cabin shell had been extended forward over the nose. The coordinates which are the least distant from the center line of the fuselage are used. This is not implemented for the tail cone to allow for upswpt tails.

2.5.1.3 Nose Shape

The aircraft nose will be modeled as the locus of two superimposed elliptical cones as shown in Figure 2.23. Each of the elliptical cones is constructed such that the top and side view planforms may be modeled by the generalized expression of equation 2.51.

\[
\left(\frac{x}{a}\right)^n + \left(\frac{y}{b}\right)^m = 1
\]  

(2.51)

Figure 2.37 defines the geometric parameters used to describe the shape of the nose. Using the parameters shown in Figure 2.37 the coordinates at any point on the nose will be determined by the following procedure.

Each of the elliptical cones used for the nose will be such that the top and side view planforms may be described by the general equation 2.51. Appendix A of this report explains the use of elliptical cones as described in Reference 9. Briefly, the shape of the elliptical cone is determined as follows.

Given a specific cone shape, a rectangle may be superimposed about half the planform as shown in Figure 2.38. By constructing the diagonals, OS and OT, it is possible to define the shape parameters \(\phi_1\) and \(\phi_2\). In general, the shape parameter \(\phi_1\) may be considered to be a taper shape parameter, while \(\phi_2\) may be
Figure 2.37 Definition of Nose Cone Geometry
defined as the bluntness parameter for the cone. These shape parameters may be used to determine the exponents of equation 2.51 as described in Appendix A.

It will be assumed that Cone N1 may be described by its top and side view shape parameters and that Cone N2 may be described by only its side view shape parameters. The method for determining these shape parameters for FUSE is discussed in detail in Appendix C.

After determining the proper shape parameters and the corresponding exponents for equation 2.51, equation 2.51 may be applied to determine the planform shapes for each cone. The planform equations for Cones N1 and N2 are expressed in equations 2.52 through 2.55, as derived from equation 2.51.

\[
\phi_1 = \frac{OP}{OA} \quad \phi_2 = \frac{OQ}{OA}
\]

Figure 2.38 Definition of Elliptical Cone Shape Parameters

For Cone N1

Side View:

\[
z_{\text{m1}}|_x = z_{N1} \left[ 1 - \left( \frac{z_{\text{N1}} - x}{z_{N1}} \right)^{n_{N1}} \right]^{1/m_{N1}}
\]  

(2.52)
Top View:

\[ y_{m1} \left| x \right. = y_{N1} \left[ 1 - \left( \frac{x_{N1} - x}{x_{N1}} \right)^{n_{y1}} \right]^{1/m_{y1}} \]  

(2.53)

where: \( m_{N1} \) and \( n_{N1} \) are derived from Cone N1 side view shape parameters \( \phi_{11} \) and \( \phi_{21} \);

and: \( m_{y1} \) and \( n_{y1} \) are derived from Cone N1 top view shape parameters, \( \phi_{y1} \) and \( \phi_{y2} \).

For Cone N2

Side View:

\[ y_{m2} \left| x \right. = \begin{cases} \frac{H}{2} \left[ 1 - \left( \frac{x_{N1} - x}{x_{N2}} \right)^{n_{N2}} \right]^{1/m_{N2}} & \text{for } x > (x_{N1} - x_{N2}) \\ 0 & \text{for } x \leq (x_{N1} - x_{N2}) \end{cases} \]  

(2.54)

Top View:

\[ y_{m2} \left| x \right. = \begin{cases} \frac{W}{2} \left[ 1 - \left( \frac{x_{N1} - x}{x_{N2}} \right)^{n_{N2}} \right]^{1/m_{N2}} & \text{for } x > (x_{N1} - x_{N2}) \\ 0 & \text{for } x \leq (x_{N1} - x_{N2}) \end{cases} \]  

(2.55)

where: \( m_{N2} \) and \( n_{N2} \) are derived from Cone N2 side view shape parameters.

With the planform values, \( y_{m} \) and \( z_{m} \) at any \( x \), for both cones, the cross-section shapes may be superimposed according to the methods of Section 2.5.1.2. As stated in Section 2.5.1.1, the cross-section at each lengthwise segment will be divided into a specified number of radial segments. To attempt to place the
nodes as effectively as possible, for use in the NCSU BODY program, the following method will be used.

Figure 2.39 pictures the orientation of cones N1 and N2. A line, CL, has been constructed from the tip of Cone N1 to the centroid at the base of Cone N2.

\[
\mathbf{z}_{CL} = \left( \frac{-z_{NO}}{\mathbf{z}_N} \right) \mathbf{x} + z_{NO} \quad (2.56)
\]

This line will be used as a centerline from which the radial divisions will be constructed.

For \( x \leq (l_{N1} - l_{N2}) \) nodes will only be determined for Cone N1. For \( x > (l_{N1} - l_{N2}) \), the distance of the j'th node for each cone from CL will be used to decide which node will be retained. The distance will be determined as:

\[
r = \sqrt{y^2 + (z - z_{CL})^2} \quad (2.57)
\]
The node resulting in the greater value of \( r \) will be used.

2.5.1.4 **Cabin (Utility Section) Shape**

The cabin will be modelled by a cylinder of a constant cross-section. No offsets will be used for the cabin. The length of the cabin will be represented as \( l_u \). The cross-section at any point may be represented by the method of Section 2.5.1.2.

2.5.1.5 **Tail Cone Shape**

The tail cone shape will be modelled as an elliptical cone in much the same manner as Cone N1 of the nose. At present, the shape parameters used by FUSE for the tail cone are the same for both the top and side planform shapes. For this reason, an average of the top and the side view shape parameters is advised for input data to the program. This is discussed in Appendix C in more detail.

With the shape parameters and subsequently the exponents for the equation, the planform shapes may be expressed as in equations 2.58 and 2.59. Figure 2.40 describes the geometric parameters used to describe the tail cone.

\[
\text{Side View: } z_{mc} = \frac{H}{2} \left[ 1 - \left( \frac{x'}{l_c} \right)^{n_c} \right]^{1/m_c} \\
\text{Top View: } y_{mc} = \frac{W}{2} \left[ 1 - \left( \frac{x'}{l_c} \right)^{n_c} \right]^{1/m_c} \\
\text{Where: } x' = x - (l_{N1} + l_u)
\]

As with Cone N1 of the nose, to allow for upswept tail cone, provision has been made in FUSE for a vertical offset for the tail cone of the form:

2.75
Figure 2.40 Definition of Tail Cone Geometry
The cross-section will, again, be determined according to the method of Section 2.5.1.2.

2.5.2 Program Description

Using the model developed in Section 2.5.1 a program was written in the Fortran IV computer language to compute the coordinates of nodes for finite-element analysis applications for commuter aircraft fuselages. Figure 2.41 presents a simplified flowchart of the program. A complete listing for the program is presented in Appendix C of this report.

The program calls one subroutine to aid in the computation of the node coordinates, CONSHP. CONSHP is a short iteration subroutine used to determine the planform equation exponents from the elliptical cone shape parameters, as stated in Section 2.5.1. A description of the method used in CONSHP is presented as part of the explanation of the elliptical cone method in Appendix A.

It should be noted that fuselage node coordinates are stored in a three-dimensional matrix, SFUS (I, J, K). SFUS has been dimensioned as a 60 x 30 x 3 matrix. This allows a maximum of 1,711 panels for each fuselage. Although this may appear to be an excessive number of panels, the dimensioning was chosen to allow maximum flexibility in choosing lengthwise and radial segment distributions for structural or aerodynamic applications. The I value is the number of the lengthwise segment. The J value is the number of the radial segment, numbered from bottom to top. The K value is the x, y, or z coordinate, with the K values of 1, 2, and 3 corresponding to x, y, and z, respectively.

Although at present, they are not output, the coordinates for the nose cones N1 and N2 are also stored in three-dimensional

\[ z_0 = q_{c1}(x') + q_{c2}(x')^2 \] (2.60)
INPUT PROGRAM MODE:
1) DESIGN
2) SIMULATE
   (INTERACTIVE)

SELECT OUTPUT OPTIONS:
1) DIMENSION
2) COORDINATES
3) TOTAL WETTED AREA
4) PANEL AREAS AND RATIOS
5) FUSELAGE PLOT
   (INTERACTIVE)

SIMULATION?
F
INPUT:
DESIGN PARAMETERS
   (INTERACTIVE)

T
INPUT:
CONFIGURATION DATA
   (FROM PERMFILE "03")

PRINT DIMENSIONS?
F 3

T
OUTPUT:
CONFIGURATION DIMENSIONS

2

Figure 2.41  Simplified Flowchart for FUSE
Figure 2.41 (continued)

2.79
SHIFT COORDINATES FOR NCSU BODY PROGRAM

FILE COORDINATES?

T → OUTPUT: COORDINATES TO PERMFILE "07"

F

COMPUTE: PANEL AREAS AND RATIOS

OUTPUT WETTED AREA?

T → OUTPUT: TOTAL WETTED AREA

F

OUTPUT AREAS AND RATIOS?

T → OUTPUT: PANEL AREAS AND RATIOS

F

OUTPUT COORDINATES?

T → OUTPUT: FUSELAGE COORDINATES

F

PLOT FUSELAGE?

PLOT: FUSELAGE THREE-VIEW

NEW RUN?

F → STOP

T → 1

Figure 2.41 (continued)

2.80
arrays. These arrays, SNOS1(I, J, K) and SNOS2(I, J, K), are set up in a similar manner to SFUS. The intent is to eventually evaluate the individual nose shells for crew compartment volume, visibility, landing gear stowage, etc.

The program may be operated in either a design mode or a simulation mode. In the simulation mode, the program will read shape parameters for a particular aircraft configuration from a data file already stored on disc. The logical unit number for the READ statements in this case is "03." In the design mode the program will ask the user to input the necessary variables in a question-and-answer process.

One of the original intents for FUSE was to prepare data for use with the NCSU BODY program (or Reference 20) to enable parametric studies for fuselage drag optimization. For this reason the program will re-orient the fuselage coordinates and output them to a disc permfile in a format useful to the BODY program, if desired. The logical unit number for the WRITE statements in this case is "07." Several other output options are available as well. These are discussed in Appendix C.

2.5.3 Program Results

To test FUSE, several simulations of actual aircraft were made. Two of these simulations are presented here as Figures 2.42 and 2.43. Figure 2.42 represents a simulation of the Gates-Learjet Model 35/36. Figure 2.43 represents a simulation of the Fokker-VFW F28 Mk. 4000.

In both cases, the simulation seems to represent the fuselage shape with reasonable accuracy. Discrepancies, however, are apparent. Because of the straight-line-segment method used, for instance, the nose and tail become pointed. The accuracy by which the windshield/body intersection is modelled depends upon the number of panels specified for the nose section of the fuselage. Note, also, that the "flat" portion of the F28 tail cone has been averaged into the overall rounded shape. The mismatch of tail cone lengths is a result of a miscalculation for input data.
Figure 2.42 Gates Learjet 35/36 Simulation - 580 Panels
Figure 2.43 Fokker F28 MK. 4000 Simulation - 600 Panels
It is believed that when the analysis of the fuselages is completed using BODY, the results will be close. Also, at that time, to check the sensitivity of the method slight modifications in the shape and geometry will be made to document the effects of simulation discrepancies on aerodynamic predictions of BODY. The most considerable problem to be encountered was the choosing of the fuselage divisions to insure accuracy according to the constraints of Reference 20.

Although several conceptual designs have also been made, hard-copy plots were not available. Preliminary indications are that FUSE-generated designs are reasonable.
CHAPTER 3 WING CONFIGURATION STUDIES

The project objectives as outlined in Chapter 1 called for performing a short study of wing sizing methods and considering a rational approach to wing placement. Although it has not been possible to completely meet the objectives in this area, this chapter will discuss briefly one alternative method to the GASP method for wing sizing, and a method that was considered for wing placement. Section 3.1 will discuss the wing sizing method, and Section 3.2 will describe the wing placement method.

3.1 Wing Sizing

It was proposed to consider the methods of Laurence Loftin of NASA-Langley (References 3, 21, 22, and 23) as an alternative method to sizing the aircraft wing for optimization studies. Time permitted only a quick look at the methods involved, and no formal evaluation was possible.

The methods described by References 3, 21, 22, and 23 may be applied to either jet-propelled or propeller-driven aircraft. The methods used are based on data collected from several aircraft in each category.

The propeller-driven aircraft sizing methods were based on the characteristics of over one hundred forty different aircraft in a gross weight range from approximately 1000 lbs. to over 100,000 lbs. The maximum speed range of these aircraft covered a range from about 100 MPH to over 500 MPH. The methods are intended to size the aircraft to one or more of the following performance objectives (Reference 21):

A. Airport Performance
   1. Stalling Speed
   2. Landing Field Length
3. Take-off Field Length
4. Climb Performance

B. Cruise Performance
1. Maximum or cruising speed usually at a specified altitude and power setting
2. Range, again at a specified altitude and power setting
3. Payload

By specifying these performance objectives, and by using the aircraft data and the analysis methods proposed, it is possible to rapidly estimate the following aircraft characteristics:

- Gross Weight
- Empty Weight
- Fuel Weight
- Wing Area and Wing Loading
- Power and Power Loading
- Performance Characteristics at Values of Altitude and Power other than those Specified

Figure 3.1 provides a simplified flowchart of the method as applied to propeller-driven aircraft.

The performance and size estimation method for jet-propelled aircraft was accomplished in a similar manner. The methods were based on the characteristics of approximately 35 aircraft with gross weight ranging from about 10,500 to 800,000 lbs. For the jet-propelled aircraft the following performance objectives were considered (Reference 22):

A. Airport Performance
1. FAR (Federal Air Regulations) landing field length including missed approach requirement
2. FAR take-off field length including second segment climb requirement
Figure 3.1 Aircraft Sizing Flow Diagram for Propeller-Driven Aircraft (Reproduced from Reference 21)
B. **Cruise Performance**

1. Cruise speed and altitude
2. Range
3. Payload

In this case by using the performance objectives, the aircraft data, and the proposed analysis methods, the following aircraft characteristics may be rapidly estimated:

- Gross Weight
- Fuel Weight
- Wing Area and Wing Loading
- Thrust and Thrust Loading
- Altitude for Cruise, if not specified

Figure 3.2 provides a simplified flowchart of the methods as applied to jet-propelled aircraft.

Although a formal evaluation of the methods was not made, a preliminary study of the method indicated that very good results could be expected. The intent of Loftin's method was to allow one person to rapidly estimate the performance and size of an aircraft without having to rely on expensive computer aids. As a result the method is very much oriented towards graphical approximations. The GASP, on the other hand, accomplishes the same basic objectives through computer applications. At this time, it is not felt necessary to pursue the evaluations of Loftin's approach for use in the design optimization of commuter airplanes.

3.2 **Wing Placement**

When the proposal for the first continuation of this research project was submitted to NASA-Ames in December 1976 (Reference 2), a misunderstanding of the wing location method used by the GASP inclined KU-FRL personnel to believe that an improved method was available. This method, provided in
Figure 3.2 Aircraft Sizing Flow Diagram for Jet-Propelled Aircraft
(Reproduced from Reference 22)
Chapter 8 of Reference 9, however, was in fact essentially what the GASP already used. For this reason work to incorporate a wing location routine based on Reference 9 was discontinued.

One other aspect of the GASP wing location routine did raise some questions. In locating the wing to provide a specified static margin value, the GASP assumes that the aerodynamic center of the wing (alone) is at 25% of the MAC. This is satisfactory for essentially upswept wings ($\alpha_{LE} < 10^\circ$) at low Mach numbers ($M < 0.3$). For business jet configurations this is not necessarily the case. The methods of Reference 14 were to be used to locate the aerodynamic center, given a specific wing geometry at cruise Mach number, but time did not permit the completion of the associated routines. Also, it appeared that, in the GASP, it was assumed that the effect of the body is to shift the aerodynamic center aft. Subsequently it was assumed in the GASP that any static margin allowed would be conservative. On the other hand, the effect of the body is, in fact, to shift the aerodynamic center forward, tending to destabilize the aircraft. For this reason it was intended to use the Multhopp strip integration routine mentioned in Section 2.3 to compute the body effect and then to iterate to find the wing location that would result in the proper static margin. Figure 3.3 presents a flow diagram to illustrate this approach.

As the GASP is still inoperational, these methods have not yet been implemented.
Figure 3.3 Flow Diagram of the Proposed Wing Location Approach
CHAPTER 4 WETTED AREA, DRAG, AND WEIGHT STUDIES

Towards the objective of determining a minimum weight and drag configuration to aid in minimizing DOC, studies were made to determine whether a minimum drag configuration could be defined for the fuselage. Weight and drag studies were both to have been conducted using the GASP, but due to the inoperational status of the program this has not been possible. It was also hoped that additional drag data could have been compiled to compare with the GASP results by using the NCSU BODY program of Reference 20. Higher priorities had to be placed on the GASP program, and therefore the BODY program transliteration process was put aside.

Wetted area studies were conducted using FUSE for both actual and conceptual aircraft. As wetted area may be related to both drag and weight, some implication of the wetted area study may be used to predict what might be expected with drag and weight. The wetted area study will be discussed in Section 4.1. Section 4.2 redocuments the slipstream drag study presented in Reference 15.

4.1 Wetted Area Studies

The zero-lift drag of an airplane is proportional to its wetted area as shown in equation 2.4. The weight of the fuselage structure may be said to be proportional to its wetted area to the power 1.2, as shown in equation 2.21. Therefore by studying the wetted areas of various airplane configurations, it should become possible to derive some conclusions as to the trends in weight and drag to be expected.

Early in the research program, an attempt was made to correlate both total fuselage wetted area and fuselage section (nose, cabin, and tail) wetted area with their characteristic length. Data were compiled using wetted areas either acquired directly from the airframe manufacturer, or acquired by estimations from available
drawings. In an attempt to derive mathematical relationships, linear, exponential, and logarithmic least-squares curve-fits were applied to these data. These relationships are presented as Figures 4.1 through 4.12.* The results of these correlations were not very promising.

With the completion of FUSE (Section 2.5) another approach to determining wetted areas became available. Several aircraft were modelled using FUSE and the resultant wetted areas were compared with their actual wetted areas. These results are presented as Figure 4.13. With the exception of the Fokker F28, FUSE seems to provide good results.

Having determined that the wetted areas computed by FUSE were reasonable, a quick study was performed to determine the effect of cabin seating arrangement and total passenger capacity on fuselage wetted area. Conceptual aircraft were designed by FUSE to consider 10, 20, and 30 passengers in 2, 3, and 4 seats abreast configurations. Also these designs were made for circular cross-sections and for round-rectangular sections with a round-off radii value of 0.5. In all cases the default** values for a piston aircraft were used for the shape parameters and ratios. Adequate comfort level values were assumed, and baggage compartments allowing for 5 cu. ft. of baggage per passenger were also included. The significant parameters for each configuration are presented in Table 4.1. Figure 4.14 presents a plot of fuselage wetted area as a function of passengers for the circular fuselage configurations. Similarly, Figure 4.15 presents the results for the rounded-rectangular fuselage configurations.

From Figure 4.14 note that for all of the passenger capacities considered the number of seats abreast seems to be the controlling factor. For the twenty to thirty passenger range, however, the

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*In figures 4.1 through 4.12, gross wetted area is the wetted area of the entire fuselage; net wetted area is gross wetted area minus the area of wing-body and tail-body intersections.

**See footnote page

4.2
Table 4.1 Conceptual Aircraft Design Parameters for the Wetted Area Study

Note: 1) Adequate Comfort Level is Assumed

2) Baggage Compartment ~ 5 cu. ft./passenger

<table>
<thead>
<tr>
<th>Conceptual Config.</th>
<th>Total Passengers</th>
<th>Seats Abreast</th>
<th>Round-off Radii (ft)</th>
<th>Outside Width (ft)</th>
<th>Outside Height (ft)</th>
<th>Nose Length (ft)</th>
<th>Cabin Length (ft)</th>
<th>Tail Length (ft)</th>
<th>Wetted Area (ft²)</th>
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</table>
1400 NOTE:
1) Data from Ref. 17
2) Linear Curve Fit;
\[ S_{\text{wet}} = 18.14 \ell_B - 202.7 \]
\[ r^2 = 0.86 \]

Figure 4.1 Linear Correlation Between Fuselage Length and Fuselage Wetted Area
NOTE:
1) Data from Ref 17
2) Exponential Curve Fit;

\[ S_{\text{wet}} = 118.2^{0.036} \ell_B \]

\[ r^2 = 0.85 \]

Figure 4.2 Exponential Correlation Between Fuselage Length and Fuselage Wetted Area
NOTE:
1) Data from Ref. 17
2) Logarithmic Curve Fit;
   \[ S_{\text{wet}} = -1894 + 665.9 \ln(L_B) \]
   \[ r^2 = 0.79 \]

Figure 4.3 Logarithmic Correlation between Fuselage Length and Fuselage Net Wetted Area
NOTE:
1) Data from Ref. 17
2) Linear Curve Fit:
   \[ S_{\text{wet}} = 10.1 (L_N) + 10.83 \]
   \[ r^2 = 0.69 \]

Figure 4.4 Linear Correlation Between Nose Length and Nose Wetted Area
NOTE:
1) Data from Ref. 17
2) Exponential Curve Fit;
   \[ S_{\text{wet}} = 65.5 \times e^{0.06\ell_N} \]
   \[ r^2 = 0.31 \]

Figure 4.5 Exponential Correlation Between Nose Length and Nose Wetted Area
NOTE:
1) Data from Ref. 17
2) Logarithmic Curve Fit:
\[ S_{\text{wet}} = -126.2 + 105 \ln(l_N) \]
\[ r^2 = 0.40 \]

Figure 4.6 Logarithmic Correlation Between Nose Length and Nose Wetted Area
NOTE:
1) Data from Ref. 17
2) Linear Curve Fit:
\[ S_{\text{wet}} = 20.48 \, l_U - 25.6 \]
\[ r^2 = 0.94 \]

Figure 4.7 Linear Correlation Between Cabin Length and Cabin Wetted Area
NOTE:
1) Data from Ref. 17
2) Exponential Curve Fit;
   \[ S_{\text{wet}} = 62.76^{0.10} L_U \]
   \[ r^2 = 0.90 \]

Figure 4.8 Exponential Correlation Between Cabin Length and Cabin Wetted Area
NOTE:
1) Data from Ref. 17
2) Logarithmic Curve Fit;
\[ S_{\text{wet}} = -424.2 + 263.76 \ln (L_u) \]
\[ r^2 = 0.89 \]

Figure 4.9 Logarithmic Correlation Between Cabin Length and Cabin Wetted Area
NOTE:
1) Data from Ref. 17
2) Linear Curve Fit;
   \[ S_{\text{wet}} = 9.33 l_C - 3.92 \]
   \[ r^2 = 0.90 \]

Figure 4.10 Linear Correlation Between Tail Cone Length and Tail Cone Wetted Area
NOTE:
1) Data from Ref. 17
2) Exponential Curve Fit;

\[ S_{\text{wet}} = 45.7^{0.07(L_C)} \]

\[ r^2 = 0.79 \]

Figure 4.11 Exponential Correlation Between Tail Cone Length and Tail Cone Wetted Area
NOTE:
1) Data from Ref. 17
2) Logarithmic Curve Fit:
   \[ S_{\text{wet}} = -281.8 + 155.1 \ln (L_C) \]
   \[ r^2 = 0.80 \]

Figure 4.12 Logarithmic Correlation Between Tail Cone Length and Tail Cone Wetted Area
Figure 4.13 Comparison of Actual Fuselage Wetted Areas with Wetted Areas Predicted by FUSE
Figure 4.14  Gross Wetted Area as a Function of Passengers for Circular Fuselages
NOTE:
1) Round-off Radii = 1.0
2) Wetted Area Predicted by Fuse
3) Baggage 5 ft./Pass.
4) Adequate Comfort Level
5) Seats Abreast:
- ~ 2
- ~ 3
- ~ 5

Figure 4.15 Gross Wetted Area as a Function of Passengers for Rounded-Rectangular Fuselages
wetted areas for the 2 and 3 seats abreast configurations are very close. Considering drag, in this case, the 2 seats abreast configuration is still best. A longer fuselage length results in higher Reynolds numbers and therefore lower skin friction coefficients. From a weight standpoint, as weight may be considered as proportional to wetted area to the power of 1.2, the 2 seats abreast configuration also prevails.

Figure 4.15 produced some rather unexpected results. Note here, that the wetted areas for the 2 seats abreast configurations rapidly become very much greater than the other seating arrangements. Checking Table 4.1, it is apparent that the nose cone lengths for this configuration appear overly large. This might indicate that the standard crewbox is too large for this configuration. Looking at the 3 and 4 seats abreast configurations, note that 4 seats abreast become more efficient, from a wetted area standpoint above 16 passengers. This could mean a drag trade-off as the 3 seats abreast configurations will have longer fuselages and therefore lower skin friction coefficients. From a weight standpoint the 4 seats abreast configuration is still preferable.

These assumptions and conclusions are of course based solely on the wetted areas. Such factors as comfort, pressurization, ease of construction, etc., should also be considered before selecting a configuration.

4.2 Approach to the Prediction of Zero-Lift Drag in a Propeller Slipstream

When a rotating propeller is working in the presence of a body (wing, nacelle, fuselage), the flow through the propeller disc and about the body will change. The flow through the propeller disc will change because it will work in a perturbed flow field. These perturbations alter the local angle of attack and effective airspeed at each blade section, and thus the overall propeller characteristics.
The flow over the body will change due to the existence of a slipstream. The body can be either immersed in the slipstream or be close to it; in either case the airflow about the body will change. As a result, lift and drag of the aircraft parts in the slipstream and propeller thrust and power-required will change.

Figure 4.16 Change in Aerodynamic Forces due to the Slipstream

The lift dependent drag is affected by propeller power in the following ways:

1. The components of propeller thrust and normal force that are parallel to and have the same direction as the wing lift reduce the wing lift required, thereby reducing the wing drag due to lift. A method to compute the magnitude of this effect can be found in Reference 24.
2. The propeller slipstream modifies the downwash and dynamic pressure over portions of the wing thus changing the wing drag due to lift. Two different methods are available to compute the magnitude of this change in drag: a) Reference 25, Section 4.6.4 (essentially empirical) and b) theoretical methods, for example: Reference 26.

Sophisticated methods exist that predict lift dependent drag changes. Therefore, the topic of this investigation will be: changes in zero-lift drag and propeller performance.

4.2.1 Zero-Lift Drag

Methods to predict the increase in zero lift drag of bodies immersed in a propeller slipstream are presented in several publications. According to all these publications, the drag increase is proportional to the average increase in dynamic pressure in the slipstream and an appropriate drag area.

Reference 24:

\[
\Delta C_{D0} = \frac{1}{S_{I}} \int \Delta q_{S} \, dS
\]  

(4.1)

where: \( \Delta q_{S} = \frac{T}{\pi R^2} \)

\( S_{I} = \) area, immersed in slipstream

Reference 28:

\[
V_{R} = \sqrt{(V_{0} + V_{1} \cos \alpha_{T})^2 + V_{1}^2 \sin^2 \alpha_{T}}
\]  

(4.2)

where: \( V_{R} = \) resultant velocity about body

\[
V_{1} = \sqrt{v^2 + \frac{2T}{\rho C_{D}}} - v
\]

= average velocity increase in slipstream far behind propeller according to momentum theory.

Reference 27:

\[
\eta_{eff} = F \times \eta_{is}
\]  

(4.3)

where: \( F = 1 - 1.558 \frac{EC_{D}S}{D_{r}} \)
Except for an additional correction factor, this method is the same as the methods of References 24 and 28 because these can also be written as follows:

with: \( \Delta q = T/\pi R^2 \)

\[
F = 1 - \frac{4}{\pi} \frac{\Sigma C_D S_I}{D^2}
\]  

(4.4)

\( \Delta D = \Delta q C_D S_I \)

Instead of \( \frac{4}{\pi} \) a factor of 1.558 is used in the Reference 27 method (22% higher). In all these methods the slipstream is represented as shown in Figure 4.17.

![Figure 4.17 Representation of Slipstream](image)

4.2.1.1 Theoretical Considerations

Theoretically it can be proven that the spanwise axial velocity distribution behind a propeller is as shown in Figure 4.18. These results have been verified experimentally.

![Figure 4.18 Spanwise Axial Velocity Distribution Behind a Propeller](image)
Figure 4.19 Curves of $H/q$ against $x$ for NACA cowling

Figure 4.19 (from Reference 29) shows distributions of total pressure increase ($H$) divided by $q$ (ambient dynamic pressure).

Considering these curves it seems unlikely that both slender and wide bodies are equally affected (as far as drag increases are concerned) by a slipstream. This suspicion is reinforced by experimental results presented in Figure 4.20 from Reference 30.

Apparently, the drag increase of bodies with a small propeller (high $d/D$) is higher than the increase in zero lift drag of bodies with a larger propeller at the same conditions (i.e. same $\Delta q_S$ and $q_0$).

N.B.: $\frac{c_a}{\frac{\Delta q}{q_0}} = \frac{\pi}{8}$
Figure 4.20 The variation of slipstream-drag coefficients with apparent propeller thrust-loading coefficients.

\[ T_{\Delta D} = \frac{\Delta D_{fus}}{\varrho V_0^2D^2} \quad T_{c_a} = \frac{T}{\varrho V_0^2D^2} \]

(a) 48-in. propeller; 12-in. nacelle (with spinner); \( d/D = 0.25 \)
(b) 48-in. propeller; 12-in. nacelle; \( d/D = .25 \)
(c) 48-in. propeller; 16-in. nacelle; \( d/D = .33 \)
(d) 36-in. propeller; 12-in. nacelle; \( d/D = .33 \)
(e) 36-in. propeller; 16-in. nacelle; \( d/D = .44 \)
An obvious explanation for this phenomenon has not been found.

It appears necessary to know the development of the slipstream in streamwise direction accurately, in order to provide better predictions of zero-lift drag increases than those presented in Reference 24.

Reference 29 presents dynamic pressure contours in the plane of the elevator hingeline of some propeller driven airplanes. Some of the results are shown in Figure 4.21.

![Dynamic pressure contours](image)

Figure 4.21 Dynamic pressure \( (q/q_0) \) contours and inclination of the air stream in the plane of the elevator hinge line. Vectors show deviation of air flow from the free-stream direction. View looking forward. Circle shows projection of propeller center.
These figures show the velocity distribution in a cross-section of the slipstream some distance behind the propeller.

It can be seen that in this case (where the slipstream is not influenced by a body) the slipstream diameter some distance behind the propeller is still the same as the propeller diameter. The dynamic pressure distribution however is quite different from the one right behind the propeller, suggesting that mixing processes can be quite important. The results shown in Figure 4.22 are similar.

Such a slipstream development rules out quick, but accurate, predictions of its influence on drag.

Detailed theoretical or experimental investigations appear necessary to yield an accurate prediction method. A simplified approach is given in Section 4.2.1.2. At the moment, however, it seems best to use the average $Aq$ (cross sectional) in $Aq_D$ calculations.

The use of this "easy" method seems even more attractive, after looking at Figures 4.23a and b, showing dynamic pressure contours of slipstreams that have been influenced by bodies.

(a) $V/nD$, 0.489; $T_C$, 0.183; $T$, 0.373; $\alpha$, 4.1°
(a) With fillet and cowling; $T_C'$, 0.165; $T_S$, 0.248; $\alpha$, 13.7°

(b) Original condition; $T_C'$, 0.194; $T_S$, 0.292; $\alpha$, 13.7°

Figure 4.23 Dynamic pressure ($q/q_0$) contours and inclination of the airstream in the plane of the elevator hinge line. Vectors show deviation of air flow from the freestream direction. View looking forward. The McDonnell airplane.
Figure 4.22 Dynamic pressure \( (q/q_0) \) contours and inclination of the air stream in the plane of the elevator hinge line. Vectors show deviation of air flow from free-stream direction. View looking forward. Circles show projections of propeller centers. The four-engine pusher model.

It is hard to tell what the influence on fuselage drag is, of a slipstream, the dynamic pressure distribution of which has changed from the one shown at the beginning of this section, to the ones shown in Figure 4.23.

It is therefore suggested to use an average \( \Delta q_S = T/\pi R^2 \) in \( \Delta C_D \) calculations, possibly together with one of the following correction factors:

\[
\Delta D = \Delta q_S C_D S_L \times k \tag{4.5}
\]

where \( \Delta q_S = T/\pi R^2 \)

\[
k = 1 \quad \text{(Reference 24)}
\]

or: \( k = 1.224 \quad \text{(Reference 27)} \)

or: \( k = 5.8 \frac{d}{D} \quad \text{(Reference 30)} \)
An attempt has been made to show that dynamic pressure changes in streamwise direction due to mixing, etc. do exist and make accurate drag predictions virtually impossible (i.e. in a fast and simple way). But, even when a very simple theory is used (Momentum Theory), neglecting all effects like mixing and viscosity, it can be shown that the dynamic pressure (and static pressure) change in streamwise direction (Figure 4.24).

\[ \Delta q_s = \frac{T}{\pi R^2} \]

\[ \Delta P_{\text{max}} = \frac{1}{2} \frac{T}{\pi R^2} \]

Figure 4.24 Change in Pressure Behind a Propeller

In the region of the fuselage nose, \( \Delta q_s \) is apparently lower than far behind the propeller, while \( \Delta P_p \) is higher. The influence of both effects on fuselage drag however can be approximated by assuming that \( \Delta P = 0 \) and \( \Delta q_s = \text{constant} = \Delta q \) far behind propeller. This assumption might lead to erroneous results when short fuselages with a blunt nose are considered.

4.2.1.2 A Simplified Approach to Zero-Lift Drag Prediction

An approach to the zero-lift drag prediction problem might be:

1. Calculate velocity distribution in slipstream (using continuity expression).
2. Determine \( dV/ds \) at nacelle boundary (\( s = \text{distance to nacelle boundary} \) (Inviscid).
3. Determine influence of \( dV/ds \) on boundary layer development and wall skin friction.
This approach has not been developed completely. The following explanations might help in such a development.

If local speed at a particular blade section is \( V_0 + V_a \), then there must be a speed \( V_0 + 2V_a \); in the fully developed slipstream. These speeds are along one slipstream line.

![Figure 4.25 Velocity Profile in a Slipstream](image)

With the continuity expression it follows:

\[
\frac{p}{r^{2}}(r^{2}_{pi} - r^{2}_{pi-1}) \times V^{2}_{Pav.} = \frac{p}{r^{2}}(r^{2}_{s_{i}} - r^{2}_{s_{i-1}}) \times V^{2}_{sav.}
\]

where: \( r_{pi-1} \) and \( r_{pi} \) are ends (inboard and outboard) of a blade section.

\( V_{Pav.} = \frac{r_{pi} - r_{pi-1}}{r_{pi}} \times V_{Pav.} \)

and \( r_{s_{i-1}} \) and \( r_{s_{i}} \) are boundaries of streamline tube (boundaries of which at propeller disc are: \( r_{pi-1} \) and \( r_{pi} \)) in slipstream.

\( V_{sav.} = \frac{r_{s_{i}} - r_{s_{i-1}}}{r_{s_{i}}} \times V_{0 + 2V_a} \)
Therefore: \[
(r_{pi}^2 - r_{pi-1}^2) \times (2V_0 + V_{a_i} + V_s) = \\
(r_{s_i}^2 - r_{s_i-1}^2) \times (2V_0 + 2V_{a_i} + 2V_s)^2
\]

With the known axial velocity distribution at the propeller disc (theory or experiments), the velocity distribution in the slipstream about a nacelle can be obtained by numerical integration.

Figure 4.27 Velocity Distribution in the Slipstream Around a Nacelle.
At nacelle boundary: \( V = V_0 \) (inviscid!).

According to boundary layer theory:

\[
\int_0^\delta \left( \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) dy = 0 \quad \Rightarrow \quad V(\delta) - V(0) = -\int_0^\delta \frac{\partial u}{\partial x} dy \quad (4.8)
\]

N.B. \( \delta \) is distance to wall, where viscous speed \( u \) is equal to inviscid local speed \( U = \) speed according to 1 of Section 4.2.1.2.

\[
\int_0^\delta \left[ \frac{3}{\partial x} (u^2) + \frac{\partial}{\partial y} (uv) - u \frac{\partial u}{\partial x} - \nu \frac{\partial^2 u}{\partial y^2} \right] dy = 0 \quad (4.9)
\]

where:

\[
- \nu \int_0^\delta \frac{\partial^2 u}{\partial y^2} dy = \nu \left( \frac{\partial u}{\partial y} \right)_0 - \left( \frac{\partial u}{\partial y} \right)_\delta = \frac{\tau_0}{\rho} - \nu \left( \frac{\partial u}{\partial y} \right)_\delta
\]

Rewritten:

\[
- \frac{3}{\partial x} \left[ \int_0^\delta u(U-u)dy \right] - \frac{\partial}{\partial y} \int_0^\delta (U-u)dy - \nu \left( \frac{\partial u}{\partial y} \right)_\delta = -\frac{\tau_0}{\rho} \quad (4.10)
\]

Assuming that \( U \) hardly changes over the boundary layer, and that \( \frac{du}{dy} \neq 0 \) and can be determined by the method explained in Section 3.1.2.1, the increment in skin friction drag can be determined using boundary layer theory.

A first order approximation (assuming velocity profile in boundary layer doesn't change) is:

\[
\Delta \tau = \rho \nu \left( \frac{\partial u}{\partial y} \right)_\delta = \zeta \nu \left( \frac{\partial u}{\partial y} \right) \text{at wall according to 1} \quad (4.11)
\]

Reference 30 presents a method to compute changes in lift due to a propeller slipstream. In the first part of the method velocities at the propeller disc and in the slipstream (including swirl) are calculated. This method is more complicated than the one explained above, but could also be used instead of the method in Section 3.1.2.1 to yield similar results.

4.2.2 Propeller Blockage.

Only Reference 27 gives a method to account for propeller blockage effects:

4.32
\[ J_{\text{eff}} = (1-h) J_{\text{is}} \]  \hspace{1cm} (4.12)

where \[ J_{\text{is}} = \frac{V_0}{nD} \]

\[ 1-h = 1-0.32g \frac{S}{D^2} \]

By using \( J_{\text{eff}} \) instead of \( J_{\text{is}} \) in propeller performance charts (for isolated propellers), thrust and power required of a propeller (operating in a flowfield that is perturbed by a body) can be found.

4.2.2.1 Theoretical Considerations.

In the presence of a body, the axial velocity relative to a blade section is not the velocity of advance \( V_0 \) but a velocity \( u \) caused by the blocking effect of the body. As a result, the geometric pitch will be modified:

instead of: \[ \frac{P}{D} = \frac{V}{nD} \]  \hspace{1cm} (4.13)

\[ \frac{P}{D} \frac{V}{u} = \frac{V}{nD} \]

It means that the blade sections will work at a different angle of attack.

According to Reference 29, the true propeller efficiency may be computed according to the following relation:

\[ \eta = \frac{n_{\text{is}}}{\int_0^1 \frac{dC_T}{dx} dx} \]  \hspace{1cm} (Approximate!)  \hspace{1cm} (4.14)

In order to calculate \( \eta \), both the velocity distribution through the propeller disc and the spanwise propeller load distribution have to be known. Both can be found either experimentally or theoretically. A Blade-Element theory could be used to predict theoretical load distribution. Source-sink distributions can be convenient when calculating velocity distributions in the propeller disc. Figure 4.28 shows the body shapes that can be simulated by a combination of 1 sink and 1 source.

Figure 4.29 shows some \( u/v \) distributions in the propeller disc according to this potential flow theory.
Figure 4.28 Body Shapes Simulated by a Source/Sink Combination

Figure 4.29 Velocity Distributions in the Propeller Disc by Potential Flow Theory
4.2.2.2 Experimental Results.

Some of the results presented in Reference 29 are shown in Figure 4.30.

![Figure 4.30 Comparison of apparent propeller efficiency envelopes for four body shapes.](image)

Figure 4.30 Comparison of apparent propeller efficiency envelopes for four body shapes.

![Figure 4.31 Velocity distribution of propeller (propeller removed). V, 93 miles per hour.](image)

Figure 4.31 Velocity distribution of propeller (propeller removed). V, 93 miles per hour.

Depending on the accuracy required, either the method of Reference 26 can be used, or a blade element theory combined with a method that predicts velocity distributions in the propeller disc.

Further studies should be conducted to develop this approach to the estimation of slipstream drag (along with the approach of Reference 26) into a programmable method. Eventually the intent is to include this method into the drag estimation portion of the GASP.
CHAPTER 5 THE GENERAL AVIATION SYNTHESIS PROGRAM, GASP

As has been stated at several points throughout this report, the means by which all of the design optimization methods were to be implemented was the General Aviation Synthesis Program (GASP) developed for the NASA-Ames research center by the University of Minnesota. The KU-FRL research staff has been working continuously now for approximately one year to put an up-to-date version of the GASP into an operational status on the University of Kansas Honeywell 66/60 computer. At this time the program is still not implemented on the University of Kansas facilities, although it is believed that for reasons that will be explained in the next section, this will be accomplished in the near future.

The difficulties encountered in putting the GASP into operational status have also prevented the KU-FRL research staff from making revisions to the GASP to reflect the research that has been completed. This chapter will therefore discuss, first, the steps taken in attempting to transliterate the GASP, in Section 5.1, and second, how the design constraints were to be implemented in the GASP, in Section 5.2.

5.1 Transliteration Process

A copy of the GASP was first received at the KU-FRL in June 1976. The program was forwarded to the KU-FRL by Tom Galloway at NASA-Ames on magnetic tape. Also provided with the magnetic tape were a complete listing, a copy of Reference 31 describing the general flow of the program, a description of input parameters, and a sample output. Unfortunately, the magnetic tape parity was incompatible with the University of Kansas computer system. The tape was returned to NASA-Ames for a copy with the proper parity. The new magnetic tape was in the following format:

- IBM compatible
- 9-track
Transliteration procedures were started for this tape; and although all compilation errors were finally eliminated, the program could not be coerced to execute. At that time no explanation was available.

A card deck version of the GASP was acquired from the Cessna Aircraft Company with the assistance of Don Halverstadt. This version was designed to be run on an IBM 360 computer system. After completing preliminary transliterations it was determined that the free-field input routines of this version and the previous NASA version were incompatible with the Honeywell 66/60 system. The Cessna input routines proved easier to revise. In early March two runs were made of the Cessna version with only minor difficulties.

The Cessna version of the GASP was an older version and consequently it became necessary to update the program to reflect NASA revisions. Revisions were made to the program using the Honeywell 66/60 timesharing system editor and by storing the GASP on disc subroutine by subroutine. This process was proving to be extremely time consuming with no guarantee of success. It was decided to acquire a new magnetic tape from NASA-Ames with the intent of splicing the revised Cessna input routines onto a transliterated NASA version. This was the status at the end of June 1977. Fiscal year end administration difficulties prevented the completion of this process.

Negotiations have been carried out with the University of Kansas Computation Center to gain what is referred to as "internal project status" for the GASP. This status has now been assigned by the computation center, and they will implement the program using its more experienced staff at no charge.
Previously it was understood that such status would not be possible for the GASP. To have the GASP implemented on an "external project status" would have resulted in prohibitive costs. It is expected that the GASP will be finally operational by the end of September.

5.2 Implementation of Design Constraints

In Chapter 1 it was assumed that the aircraft configuration could be designed to meet four specific constraints:

a) Utility Constraints  
b) Stability and Control Constraints  
c) Mission Constraints  
d) Performance Constraints

The GASP already will account for the last two constraints adequately and therefore those constraints will not be discussed here. The utility and stability and control constraints were in need of some revision, however. The methods that were to be used to revise the GASP accordingly will be discussed in the following paragraphs.

5.2.1 Cabin-Utility Constraints

In Chapter 2 a number of methods for sizing for the utility constraints were discussed. These methods were brought together in the form of the design mode of the program FUSE. It was intended to replace the fuselage sizing portion of the subroutine SIZE in the GASP with a call to a subroutine FUSIZE. FUSIZE would have consisted of the design mode and wetted area calculation portion of FUSE. This could have been readily implemented with one minor exception. The Honeywell 66/60 allows only 59 arguments for SIZE. This would mean that to add the needed data for FUSIZE, a namelist input method would be necessary. This, however, should present no great difficulties.
5.2.2 Stability and Control Constraints

Two forms of stability and control constraints were considered for implementation in the GASP—static constraints and dynamic constraints. The methods that were considered for each will be discussed in turn.

The static stability and control constraints that were considered were: longitudinal static stability in the stick-fixed case, implemented through $C_{m \alpha}$; and directional static stability, implemented through $C_{n \beta}$. Both constraints were to have been accomplished in the empennage sizing process in the following manner. The first time the SIZE is called, the weight and c.g. data are usually lacking. As the c.g. location is required for both constraints, it was intended to use $\bar{V}$ methods to size the empennage. The next time SIZE is called, when a c.g. location is known, the subroutines STABAREA and VERTAREA (Section 2.3) would be used to size the horizontal and vertical tails for the stability constraints. In this manner the preliminary use of a $\bar{V}$ method would provide the required "seeds" for the iterative processes of STABAREA and VERTAREA.

The dynamic stability and control characteristics presented more of a problem. To determine the dynamic characteristics of the aircraft all of the non-dimensional stability and control derivatives, and the airplane inertias must be known. It was intended that rather than to attempt to constrain the design for dynamic characteristics, the configuration would simply be analyzed for dynamic stability and control characteristics. To accomplish this the non-dimensional derivatives would be determined using the methods of Reference 14, and the analysis would be implemented by appending the appropriate portion of the program described in Reference 32 to the GASP. An inertia determining routine would also be required, but this was not felt to present any great difficulty.

These characteristics, plus a number of others, will be the subject of the next chapter.
CHAPTER 6 PROPOSED FUTURE RESEARCH

With the exception of integrating the design methods into the GASP, most of the design constraints mentioned in Chapter 1 were accounted for. Only the stability and control constraints have not been adequately enforced. Considering this, a proposal for the continuation of the project was submitted to NASA-Ames (Reference 33), placing sole emphasis on stability and control methods. This chapter will present what is essentially a reprint of the statement of work of that proposal.

Care will be exercised not to duplicate any work already done in this area by other GASP investigators.

6.1 Objectives

It is proposed that work on the design optimization of short haul and commuter airplanes be continued with the following objectives:

a) To determine those stability and control characteristics which are critical to the preliminary design process.

b) To evaluate stability and control analysis methods currently available to determine those methods most appropriate for the preliminary design function which GASP performs.

c) To determine how the methods of b) may be used to provide the proper constraints and/or analysis functions for GASP.

d) To develop the appropriate subroutines for the methods of c) and how they may be appended into GASP.

In line with these objectives, emphasis will be placed on the stability and control characteristics of both jet and propeller driven airplanes. Also specific attention will be given to the determination of the following stability and control characteristics in the preliminary design process:
a) Static longitudinal stability;
b) Static directional stability;
c) Engine-out control;
d) Calculation of rotation velocity, \( V_R \);
e) Longitudinal dynamic stability;
f) Lateral-directional dynamic stability;
g) Trim at low speed and forward C.G.

The following section will outline briefly the approach that will be taken to meet the objectives with respect to the above stability and control characteristics.

6.2 Stability and Control Analysis Methods

The primary references that will be used to determine and evaluate the stability and control analysis methods will be References 9, 14, 24, and 34. In the following paragraphs each of the stability and control characteristics listed in the previous section and its proposed analysis method will be discussed briefly.

6.2.1 Static Longitudinal Stability

Using the methods of References 14 and 34, the configuration will be analyzed for static margin (\( \frac{dC_m}{dC_L} \)), static longitudinal stability (\( C_m \)), and the neutral point for both and stick-fixed and stick-free cases. To facilitate the calculation of these values a simple Mullthopp integration procedure for the body (and engine nacelles in the case of wing-mounted engines; see Section 2.3) will be used. Correlations with on-hand tunnel data actual configurations will be made.

Using Equation 4.35 on page 4.23 of Reference 34, the stick-fixed neutral point will be defined as in Equation 6.1. The stick-free neutral point will be defined by Equation 5.99 on page 5.47 of Reference 34 as shown in Equation 6.2. In both cases the variables are as defined in Reference 34.
Stick-Fixed Case:

\[
\overline{X}_{c.g.} (C_{m\alpha} = 0) = \frac{C_{L_{\alpha}}}{C_{L_{\alpha}}^{\alpha_{WB}}} \left( \frac{S_H}{S} \right) \eta_H \frac{S_H}{S} \overline{X}_{AC_{H}} (1 - \frac{d\gamma}{d\alpha})
\]

\[
\overline{X}_{c.g.} (C_{m\alpha} = 0) = N.P. = \frac{C_{L_{\alpha}}}{C_{L_{\alpha}}^{\alpha_{WB}}} \left( \frac{S_H}{S} \right) \eta_H \frac{S_H}{S} (1 - \frac{d\gamma}{d\alpha})
\]

Stick-Free Case:

\[
\overline{X}_{c.g.} (C_{m\alpha} = 0) = \frac{C_{L_{\alpha}}}{C_{L_{\alpha}}^{\alpha_{WB}}} \left( \frac{S_H}{S} \right) \eta_H \frac{S_H}{S} \overline{X}_{AC_{H}} (1 - \frac{d\gamma}{d\alpha})(1 - \frac{C_{h_{T_{E}}}}{C_{h_{\delta_{e}}}})
\]

\[
\overline{X}_{c.g.} (C_{m\alpha} = 0) = N.P. = \frac{C_{L_{\alpha}}}{C_{L_{\alpha}}^{\alpha_{WB}}} \left( \frac{S_H}{S} \right) \eta_H \frac{S_H}{S} (1 - \frac{d\gamma}{d\alpha})(1 - \frac{C_{h_{T_{E}}}}{C_{h_{\delta_{e}}}})
\]

Propeller effects will be accounted for using the method of Reference 34, Chapter 4.

6.2.2 Static Directional Stability

Values for static directional stability, $C_{n_{B}}$, will be computed using the methods of References 9 and 14. Also propeller effects on directional stability will be considered using the methods of References 9, 24, 34, and 35.

6.2.3 Engine-Out Control

The methods of References 9 and 34 will be used to analyze the configuration for the minimum engine-out control speed, $V_{mc}$. Engine-out control will be considered from both the single-degree-of-freedom
and three-degree-of-freedom points of view. Drag due to stopped engines and/or propeller will be accounted for.

6.2.4 Calculation of Rotation Velocity, $V_R$

The speed required to rotate on take-off, $V_R$, will be calculated using the method of Reference 9.

6.2.5 Dynamic Longitudinal Stability

Dynamic longitudinal stability characteristics will be considered using the methods of both References 9 and 34 for the stick-fixed case. The dynamic longitudinal stability characteristics upon which primary emphasis will be placed will be the short period damping and undamped natural frequency. Phugoid damping and frequency will also be considered. The methods considered will include both the two-degree-of-freedom short period and phugoid approximations and the complete three-degree-of-freedom solutions of Reference 34. Also the relatively simple dynamic stability relationships of Torenbeek in Chapter 9 of Reference 9 will be investigated as to their validity.

One possible method for analyzing a configuration for dynamic stability in the GASP that will be considered will be a revised version of the dynamic stability and control analysis program document in Reference 32.

6.2.6 Lateral-Directional Dynamic Stability

In analyzing the dynamic lateral-directional stability the characteristics of the spiral, roll, and dutch roll modes will be considered. Using the methods of Reference 34, these methods will be analyzed from the approximate and complete three-degree-of-freedom points of view.
REFERENCES


4. Galloway, Tom; Correspondence of August 10, 1976.


13. Corning, G.; Supersonic and Subsonic, CTOL and VTOL, Airplane Design; Published by the author; 1960.


16. Galloway, Tom; Correspondence of October 19, 1976.


APPENDIX A USE OF POLYNOMIALS WITH FRACTIONAL EXPONENTS TO APPROXIMATE EXTERNAL AIRCRAFT LINES

Appendix B of Reference 9 describes a method for approximating the external lines of aircraft for the estimation of wetted areas, volumes, cross-sections, etc. This appendix will discuss that method and how it has been applied to fuselage shape simulation.

A1 General Background

In Reference 9, Torenbeek uses polynomials with fractional exponents to approximate the external lines of aircraft fuselages. These polynomials are of the form expressed in equation A-1.

\[ \left( \frac{X}{a} \right)^n + \left( \frac{Y}{b} \right)^m = 1; \quad m, n \geq 1 \]  

(A-1)

Figure A-1 presents a generalized curve of this type. In Reference 9, Torenbeek assumes that the plan view curves of aircraft may be generalized by equation A-1. As shown in Figure A-1, a shape parameter \( \phi \) may be determined from the plan view of an aircraft's external lines. This shape parameter may then be used to determine certain factors, \( k_A \), \( k_C \), \( k_V \) and \( k_W \), according to Figure A-2. These \( k \)-factors may
Figure A-1 Definition of Shape Parameter, ϕ, for the Generalized Curve

\[(\frac{x}{a})^n + (\frac{y}{b})^m = 1; n, m \geq 1\]

Figure A-2 Nondimensional Geometric Constants Defined by ϕ

\[k_A = \frac{\text{Area of Section OBSA}}{ab} \]
\[k_C = \frac{\text{Circumference BSA}}{a + b} \]
\[k_V = \frac{\text{Volume of Body of Revolution}}{\pi ab^2} \]
\[k_W = \frac{\text{Wetted Area of Body of Revolution}}{2\pi ab} \]
\[\phi = \frac{OP}{OA} \]

Figure A-3 Fuselage Geometry Used to Define Characteristic Areas and Volume

A.2
be used to calculate the characteristic areas and volume. Using the geometry of Figure A-3:

Cross-sectional area*:

\[ A_C = k_A b_{f_{\text{max}}} h_{f_{\text{max}}} \]  \hspace{1cm} (A-2)

Circumferential length of the cross-section:

\[ C_f = 2k_C (b_{f_{\text{max}}} + h_{f_{\text{max}}} ) \]  \hspace{1cm} (A-3)

Fuselage volume:

\[ V_f = A_C(l_c + k_V l_n + k_V l_t) \]  \hspace{1cm} (A-4)

Fuselage wetted area:

\[ S_{f_{\text{wet}}} = C_f(l_c + k_W l_n + k_W l_t) \]  \hspace{1cm} (A-5)

It may be noted that Torenbeek's method precludes the necessity of knowing the values of m and n in equation A-\text{...}. To use these curves to simulate fuselage shapes, however the values for m and n become a pre-requisite.

*At the fuselage station where the width and height are maximum
As the intent was to develop a program to aid in the preliminary design of fuselage shapes, it was desired to find a method to specify cone shapes for the nose and tail that was relatively easy to use. The use of m and n in this regard proved to be rather cumbersome, as it was difficult to develop a 'feel' for their values. As an alternative, the shape parameter, $\phi$, was chosen to specify the shapes. In addition a second shape parameter was defined to enable the determination of the values of m and n within the program. Figure A-4 defines the geometry of the two shape parameters, $\phi_1$ and $\phi_2$.

![Figure A-4 Definition of Elliptical Cone Shape Parameters](image-url)
From Figure A-4 it may be seen that $\phi_1$ may be considered to indicate the taper characteristics of the cone, while $\phi_2$ indicates the bluntness characteristics of the cone.

These shape parameters may be used to determine the values of $m$ and $n$ in the following manner. From Figure A-4 it may be seen that the line $OS$ may be represented by the equation A-6.

$$y = \frac{b}{a} x \quad (A-6)$$

Similarly the line $OT$ may be represented by equation (A-7).

$$y = \frac{b}{2a} x \quad (A-7)$$

Substituting for $y$ in equation A-1 gives the following:

$$\left(\frac{x}{a}\right)^n + \left(\frac{x}{2a}\right)^m = 1 \quad (A-8a)$$

$$\left(\frac{x}{a}\right)^n + \left(\frac{x}{2a}\right) = 1 \quad (A-8b)$$

At the points $S$ and $T$, $x$ equals $\phi_1a$ and $\phi_2a$ respectively. Substituting these values for $x$ into equations A-8 a and b respectively renders:

A.5
(\phi_1)^n + (\phi_2)^m = 1 \quad \text{(A-9a)}

(\phi_2)^n + \left(\frac{\phi_2}{2}\right)^m = 1 \quad \text{(A-9b)}

By solving these two equations for \( m \):

\[
m = \frac{\ln[1 - (\phi_1)^n]}{\ln \phi_1} \quad \text{(A-10a)}
\]

\[
m = \frac{\ln[1 - (\phi_2)^n]}{\ln \left(\frac{\phi_2}{2}\right)} \quad \text{(A-10b)}
\]

Equations A-10 may be used to solve for \( m \) and \( n \) by iteration. Such a method was used in the subroutine CONSHP, for which the listing is presented in Section A3. It should be noted here that the exponents \( m \) and \( n \) are purely a function of the shape parameters and a completely independent of the cone fineness ratio, \( a/2b \).

A2 Example Cone Shapes

To provide a 'feel' for the cone shapes resulting from various shape parameters a program was written for a Hewlett-Packard 9100B desktop calculator that would compute the exponents for and plot various cone shapes. Figures A-5 and A-6 provide cone shapes for
cones of fineness ratios \(a/2b\) of 1.5 and 2.0 respectively where \(\phi_1\) is held constant and \(\phi_2\) is varied. Table A-1 provides the values of \(m\) and \(n\) for these figures. Figures A-7 and A-8 provide cone shapes for cone fineness of 1.5 and 2, where \(\phi_2\) has been held constant and \(\phi_1\) is varied. Table A-2 presents the values of \(m\) and \(n\) for these figures.

It is interesting to note that for each value of \(\phi_1\), there is a practical range for \(\phi_2\). If \(\phi_2\) is too small, the value of \(m\) drops below 1.0 and an inflection occurs near the nose of the cone. If \(\phi_2\) is too large, the value of \(n\) drops below 1.0 and an inflection occurs near the base of the cone. It has been found that the windshield shape can sometimes best be simulated by the former of these two cases. The inflection that occurs in cone \(N_2\) will normally be buried in cone \(N_1\).
Figure A-5 Various Cone Shapes for $\frac{a}{2b} = 1.5$
Figure A-6 Various Cone Shapes for $a/2b = 2.0$

a) $\phi_1 = 0.55$

b) $\phi_1 = 0.60$

c) $\phi_1 = 0.70$

d) $\phi_1 = 0.75$
Table A-1 Values of m and n for Various Shape Parameters

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Figure A-7 Various Cone Shapes for $a/2b = 1.5$

A.11
Figure A-7 (continued)

A.12
Figure A-8  Various Cone Shapes
for a/2b - 2.0

A.13
Figure A-8 (continued)

a)

\[
\phi_1
\]

- 0.65
- 0.70
- 0.75
- 0.80

b)

\[\phi_2 = 0.90\]

- 0.70
- 0.75
- 0.80
- 0.85

f) \[\phi_2 = 0.95\]
Table A-2 Values of m and n for Various Shape Parameters

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<td>0.95</td>
<td>0.70</td>
<td>4.7857</td>
<td>0.5613</td>
</tr>
</tbody>
</table>

A.15
A3 Listing for the Subroutine CONSHP

This section contains a listing of the iterative subroutine used to determine the values of m and n.

```
1 SUBROUTINE CONSHP(PHI1, PHI2, TOL, M, N)
2 REAL M, N, M1, M2
3 J = 1
4 N = 1.0
5 DM2 = 10.0
6 10 M1 = ALOG(1.0 - (PHI1**J))/ALOG(PHI1)
7 M2 = ALOG(1.0 - (PHI2**J))/ALOG(PHI2/2.0)
8 J = J + 1
9 IF(J.EQ.100) GO TO 80
10 DM1 = M1 - M2
11 IF(DM1.LE.0.) GO TO 30
12 IF(DM1.GT.DM2) GO TO 50
13 N = N + 0.05
14 DM2 = 0.05
15 DM2 = DM1
16 GO TO 10
17 30 IF(ABS(DM1).LT.TOL) GO TO 60
18 I = I + 5
19 40 N = N - (0.05/I)
20 M1 = ALOG(1.0 - (PHI1**N))/ALOG(PHI1)
21 M2 = ALOG(1.0 - (PHI2**N))/ALOG(PHI2/2.0)
22 J = J + 1
23 IF(J.EQ.100) GO TO 80
24 DM1 = M2 - M1
25 IF(DM1.LE.0.) GO TO 20
26 IF(ABS(DM1).LT.TOL) GO TO 60
27 GO TO 40
28 50 WRITE(6,1)
29 M = 1.0
30 N = 1.0
31 GO TO 70
32 60 M = (M1 + M2)*0.5
33 70 RETURN
34 80 WRITE(6,4)
35 90 RETURN
36 1 FORMAT(10X, '***ITERATION FOR M AND N DIVERGES***'/15X, 'SET - M=1.0
37 X'/22X, 'N=1.0'//)
38 4 FORMAT(10X, '***100 STEPS COMPLETE---DID NOT CONVERGE***'//)
39 RETURN
40 ENDD
```

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR
This appendix documents the Roskam/Fillman program's use and provides a copy of the listing. Appendix B1 will define all input and output acronyms and explain how to prepare the input data. Appendix B2 will provide a complete program listing. Appendix B3 provides an example output.

B1 Preparation of Input Data

Table B-1 defines all of the input and output computer acronyms.

Table B-2 presents the input card formats. All input cards must be in the order specified by Table B-2. Data for more than one baseline aircraft may be input by stacking data decks. For multiple data decks the last card of each set of data corresponds with the first card of the next set of data. The last card of the total data deck must be blank. This tells the program that the next set of data is a null set and terminates execution.

Of particular interest are K1, K2, K3, K4, KEMP1 and KEMP2. These correspond with the weight correction factors of Section 2.3.1.3. In this case an input value of zero will result in a correction factor of unity. An input value of one will result in the corresponding non-unity correction factor.
<table>
<thead>
<tr>
<th>Acronyms</th>
<th>Variable</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEFF</td>
<td>A_EFF</td>
<td>Effective aspect ratio of the vertical tail (Reference 14)</td>
<td></td>
</tr>
<tr>
<td>AIRCRAFT</td>
<td>-</td>
<td>Aircraft or configuration name</td>
<td></td>
</tr>
<tr>
<td>AH</td>
<td>A_H</td>
<td>Horizontal tail aspect ratio</td>
<td></td>
</tr>
<tr>
<td>ALT</td>
<td>h</td>
<td>Altitude</td>
<td>ft</td>
</tr>
<tr>
<td>AV</td>
<td>A_V</td>
<td>Vertical tail aspect ratio</td>
<td></td>
</tr>
<tr>
<td>AW</td>
<td>A</td>
<td>Wing aspect ratio</td>
<td></td>
</tr>
<tr>
<td>BHO</td>
<td>b_h</td>
<td>Baseline horizontal tail span</td>
<td>ft</td>
</tr>
<tr>
<td>BVO</td>
<td>b_v</td>
<td>Baseline vertical tail span</td>
<td>ft</td>
</tr>
<tr>
<td>BW</td>
<td>b</td>
<td>Wing span</td>
<td>ft</td>
</tr>
<tr>
<td>CBAR</td>
<td>c</td>
<td>Wing mean aerodynamic chord</td>
<td>ft</td>
</tr>
<tr>
<td>CHO</td>
<td>c_H</td>
<td>Baseline horizontal tail MAC</td>
<td>ft</td>
</tr>
<tr>
<td>CMA</td>
<td>C_m_a</td>
<td>Static longitudinal stability</td>
<td>rad^{-1}</td>
</tr>
<tr>
<td>CNB</td>
<td>C_m_b</td>
<td>Static directional stability</td>
<td>rad^{-1}</td>
</tr>
<tr>
<td>CVO</td>
<td>c_V</td>
<td>Baseline vertical tail MAC</td>
<td>ft</td>
</tr>
<tr>
<td>DENSIT</td>
<td>p</td>
<td>Atmospheric density</td>
<td>slugs/ft^3</td>
</tr>
<tr>
<td>DFUS</td>
<td>D</td>
<td>Fuselage equivalent outside diameter</td>
<td>ft</td>
</tr>
</tbody>
</table>
### Table B-1 Roskam Program

**Input/Output Acronyms (Cont'd)**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Variable</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIVE</td>
<td>$V_D$</td>
<td>Dive speed</td>
<td>Knots</td>
</tr>
<tr>
<td>$\text{EP}$</td>
<td>-</td>
<td>Tail sizing span tolerance for iteration process</td>
<td>ft</td>
</tr>
<tr>
<td>ETA</td>
<td>$\eta$</td>
<td>Dynamic pressure ratio at the empennage $\frac{\bar{q}_E}{\bar{q}_W}$</td>
<td></td>
</tr>
<tr>
<td>$\text{FUSHGT}$</td>
<td>$H$</td>
<td>Fuselage outside height</td>
<td>ft</td>
</tr>
<tr>
<td>$\text{FUSWID}$</td>
<td>$W$</td>
<td>Fuselage outside width</td>
<td>ft</td>
</tr>
<tr>
<td>$H_1$</td>
<td>$h_1$</td>
<td>Fuselage height at $0.25L_B$</td>
<td>ft</td>
</tr>
<tr>
<td>$H_2$</td>
<td>$h_2$</td>
<td>Fuselage height at $0.75L_B$</td>
<td>ft</td>
</tr>
<tr>
<td>HH</td>
<td>$h_H$</td>
<td>Vertical distance from aircraft center line to horizontal tail root chord (positive down)</td>
<td>ft</td>
</tr>
<tr>
<td>IF</td>
<td>-</td>
<td>Number of different tail cones to be considered</td>
<td></td>
</tr>
<tr>
<td>$K$</td>
<td>$k$</td>
<td>Empirical vertical tail factor from Figure 7.3 of Reference 14</td>
<td></td>
</tr>
<tr>
<td>$K_1,K_2,K_3,K_4$</td>
<td>-</td>
<td>Weight estimation constant controls for fuselage (See text)</td>
<td></td>
</tr>
<tr>
<td>$\text{KAPAH}$</td>
<td>$\kappa_H$</td>
<td>Ratio of horizontal tail section lift slope to $2\pi$</td>
<td></td>
</tr>
<tr>
<td>$\text{KAPAV}$</td>
<td>$\kappa_V$</td>
<td>Ratio of vertical tail section lift slope to $2\pi$</td>
<td></td>
</tr>
<tr>
<td>$\text{KAPAW}$</td>
<td>$\kappa_W$</td>
<td>Ratio of wing section lift slope to $2\pi$</td>
<td></td>
</tr>
</tbody>
</table>
Table B-1 Roskam/Fillman Program

Input/Output Acronyms (Cont'd)

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Variable</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>KEMP1</td>
<td>$K_H$</td>
<td>Empennage weight estimation constant control</td>
<td>ft</td>
</tr>
<tr>
<td>KEMP2</td>
<td>$K_V$</td>
<td>Empennage weight estimation constant control</td>
<td>ft</td>
</tr>
<tr>
<td>LBCOLD</td>
<td>$L_B$</td>
<td>Baseline Fuselage Length</td>
<td>ft</td>
</tr>
<tr>
<td>LCI</td>
<td>$L_C$</td>
<td>Minimum tail cone length to be considered</td>
<td>ft</td>
</tr>
<tr>
<td>LCF</td>
<td>$L_C$</td>
<td>Maximum tail cone length to be considered</td>
<td>ft</td>
</tr>
<tr>
<td>LCFD</td>
<td>$L_C$</td>
<td>Baseline tail cone length</td>
<td>ft</td>
</tr>
<tr>
<td>LCHOLD</td>
<td>$L_H$</td>
<td>Baseline horizontal tail moment arm</td>
<td>ft</td>
</tr>
<tr>
<td>LN</td>
<td>$L_N$</td>
<td>Nose length</td>
<td>ft</td>
</tr>
<tr>
<td>LU</td>
<td>$L_U$</td>
<td>Cabin length</td>
<td>ft</td>
</tr>
<tr>
<td>LVOLD</td>
<td>$L_V$</td>
<td>Baseline vertical tail moment arm</td>
<td>ft</td>
</tr>
<tr>
<td>MACH</td>
<td>$M$</td>
<td>Mach number</td>
<td>ft</td>
</tr>
<tr>
<td>PHIC1</td>
<td>$\phi_{C1}$</td>
<td>Tail cone shape parameters</td>
<td>ft</td>
</tr>
<tr>
<td>PHIC2</td>
<td>$\phi_{C2}$</td>
<td>Tail cone shape parameters</td>
<td>ft</td>
</tr>
<tr>
<td>PHIN1</td>
<td>$\phi_{N1}$</td>
<td>Nose cone shape parameters</td>
<td>ft</td>
</tr>
<tr>
<td>PHIN2</td>
<td>$\phi_{N2}$</td>
<td>Nose cone shape parameters</td>
<td>ft</td>
</tr>
<tr>
<td>SBSCI</td>
<td>-</td>
<td>Side view projected area of the baseline tail cone</td>
<td>ft^2</td>
</tr>
</tbody>
</table>
Table B-1 Roskam/Fillman Program
Input/Output Acronyms (Cont'd)

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Variable</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBSN</td>
<td>-</td>
<td>Side view projected area of the nose</td>
<td>ft²</td>
</tr>
<tr>
<td>SBSU</td>
<td>-</td>
<td>Side view projected area of the cabin</td>
<td>ft²</td>
</tr>
<tr>
<td>SHO</td>
<td>$S_H$</td>
<td>Baseline horizontal tail area</td>
<td>ft²</td>
</tr>
<tr>
<td>SVU</td>
<td>$S_V$</td>
<td>Baseline vertical tail area</td>
<td>ft²</td>
</tr>
<tr>
<td>SW</td>
<td>$S$</td>
<td>Reference wing area</td>
<td>ft²</td>
</tr>
<tr>
<td>SWPHO</td>
<td>$\lambda_{PH}$</td>
<td>Baseline horizontal tail leading edge sweep</td>
<td>deg</td>
</tr>
<tr>
<td>SWPVO</td>
<td>-</td>
<td>Baseline vertical tail leading edge sweep</td>
<td>deg</td>
</tr>
<tr>
<td>TAPRH</td>
<td>$\lambda_H$</td>
<td>Horizontal tail taper ratio</td>
<td></td>
</tr>
<tr>
<td>TAPRV</td>
<td>$\lambda_V$</td>
<td>Vertical tail taper ratio</td>
<td></td>
</tr>
<tr>
<td>TAPRW</td>
<td>$\lambda$</td>
<td>Wing taper ratio</td>
<td></td>
</tr>
<tr>
<td>TAS</td>
<td>$V_T$</td>
<td>True airspeed</td>
<td>ft/sec</td>
</tr>
<tr>
<td>TEST</td>
<td>-</td>
<td>Test run number</td>
<td></td>
</tr>
<tr>
<td>THICKH</td>
<td>$(t/c)_H$</td>
<td>Horizontal tail thickness ratio</td>
<td></td>
</tr>
<tr>
<td>THICKV</td>
<td>$(t/c)_V$</td>
<td>Vertical tail thickness ratio</td>
<td></td>
</tr>
<tr>
<td>TOL</td>
<td>-</td>
<td>Tolerance for the iteration in CONSFEP (See Appendix A3)</td>
<td></td>
</tr>
<tr>
<td>ULTLOAD</td>
<td>$\eta_{ULT}$</td>
<td>Ultimate load factor</td>
<td>g's</td>
</tr>
</tbody>
</table>
Table B-1  Roskam/Fillman Program

Input/Output Acronyms (Cont'd)

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Variable</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>VISCOSS</td>
<td>$\mu$</td>
<td>Kinematic viscosity</td>
<td>$\text{ft}^2/\text{sec}$</td>
</tr>
<tr>
<td>WGROSS</td>
<td>$W_G$</td>
<td>Gross weight</td>
<td>$\text{lbs}$</td>
</tr>
<tr>
<td>WSWPLE</td>
<td>$\Lambda_{LE}$</td>
<td>Wing Leading Edge Sweep</td>
<td>deg</td>
</tr>
<tr>
<td>XBARHO</td>
<td>$-$</td>
<td>Baseline horizontal tail aerodynamic center location as a fraction of $c$</td>
<td></td>
</tr>
<tr>
<td>XBARW</td>
<td>$(\overline{X}_{ac})_W$</td>
<td>Wing aerodynamic center location as a fraction of $c$</td>
<td></td>
</tr>
<tr>
<td>XCBAR</td>
<td>$-$</td>
<td>Location of the leading edge of $c$, relative to the nose</td>
<td>ft</td>
</tr>
<tr>
<td>XCG</td>
<td>$X_{cg}$</td>
<td>Baseline c.g. location relative to the nose</td>
<td>ft</td>
</tr>
<tr>
<td>XCGH</td>
<td>$(X_{cg})_H$</td>
<td>Baseline horizontal tail c.g. relative to the nose</td>
<td>ft</td>
</tr>
<tr>
<td>XCGV</td>
<td>$(X_{cg})_V$</td>
<td>Baseline vertical tail c.g. location relative to the nose</td>
<td>ft</td>
</tr>
</tbody>
</table>
Table B-2  Roskam/Fillman Program Input Card Formats

**INPUT CARD NO. 1 - (I3A6, A2)**

<table>
<thead>
<tr>
<th>TEST</th>
<th>AIRCRAFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
</tr>
</tbody>
</table>

**INPUT CARD NO. 2 - (7F10.0)**

<table>
<thead>
<tr>
<th>TAS</th>
<th>MACH</th>
<th>DENSIT</th>
<th>VISCOS</th>
<th>ALT</th>
<th>WGROSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>21</td>
<td>31</td>
<td>41</td>
<td>51</td>
</tr>
</tbody>
</table>

**INPUT CARD NO. 3 - (7F10.0)**

<table>
<thead>
<tr>
<th>SW</th>
<th>BW</th>
<th>AW</th>
<th>CBAR</th>
<th>WSWPLE</th>
<th>TAPRW</th>
<th>XCBAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>21</td>
<td>31</td>
<td>41</td>
<td>51</td>
<td>61</td>
</tr>
</tbody>
</table>

**INPUT CARD NO. 4 - (7F10.0)**

<table>
<thead>
<tr>
<th>LBOLD</th>
<th>DFUS</th>
<th>LN</th>
<th>LV</th>
<th>LCOLD</th>
<th>FUSWID</th>
<th>FUSHGT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>21</td>
<td>31</td>
<td>41</td>
<td>51</td>
<td>61</td>
</tr>
<tr>
<td>INPUT CARD NO. 5 - (X=10.0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>H1</td>
<td>H2</td>
<td>PHIN1</td>
<td>PHIN2</td>
<td>PHIC1</td>
<td>PHIC2</td>
<td>TOL</td>
</tr>
<tr>
<td>1</td>
<td>11</td>
<td>21</td>
<td>31</td>
<td>41</td>
<td>51</td>
<td>61</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INPUT CARD NO. 6 - (412)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1</td>
</tr>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INPUT CARD NO. 7 - (X'10.0)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SHO</td>
<td>BHO</td>
<td>AH</td>
<td>SWPHO</td>
<td>TAPRM</td>
<td>THICKH</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>11</td>
<td>21</td>
<td>31</td>
<td>41</td>
<td>51</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INPUT CARD NO. 8 - (7F10.0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHOLD</td>
</tr>
<tr>
<td>1</td>
</tr>
</tbody>
</table>
Table B-2 (Continued)

INPUT CARD NO. 9 - (7F10.0)

<table>
<thead>
<tr>
<th>SVO</th>
<th>BVO</th>
<th>AV</th>
<th>SWPVO</th>
<th>TAPRV</th>
<th>THICKV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>21</td>
<td>31</td>
<td>41</td>
<td>51</td>
</tr>
</tbody>
</table>

INPUT CARD NO. 10 - (7F10.0)

<table>
<thead>
<tr>
<th>LVOLD</th>
<th>AEFF</th>
<th>K</th>
<th>EP</th>
<th>CVO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>21</td>
<td>31</td>
<td>41</td>
</tr>
</tbody>
</table>

INPUT CARD NO. 11 - (412)

<table>
<thead>
<tr>
<th>KEMP1</th>
<th>KEMP2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

INPUT CARD NO. 12 - (7F10.0)

<table>
<thead>
<tr>
<th>SBSN</th>
<th>SBSU</th>
<th>SBSC1</th>
<th>DIVE</th>
<th>VLTLOAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>21</td>
<td>31</td>
<td>41</td>
</tr>
</tbody>
</table>
Table B-2 (Continued)

<table>
<thead>
<tr>
<th>INPUT CARD NO. 13 - (7F10.0)</th>
<th>XC6</th>
<th>XC6H</th>
<th>XC6V</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>21</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INPUT CARD NO. 14 - (7F10.0)</th>
<th>XBARW</th>
<th>XBARHO</th>
<th>CMA</th>
<th>CNB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>21</td>
<td>31</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INPUT CARD NO. 15 - (7F10.0)</th>
<th>KAPAW</th>
<th>KAPAH</th>
<th>KAPAV</th>
<th>ETA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>21</td>
<td>31</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INPUT CARD NO. 16 - (3F10.0, IX, 13)</th>
<th>LC1</th>
<th>LCP</th>
<th>IF1</th>
<th>IF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>21</td>
<td>31</td>
<td>32</td>
</tr>
</tbody>
</table>
INPUT CARD NO. 17 - SHOULD BE BLANK AS THE LAST CARD OF THE TOTAL DATA DECK. OTHERWISE, THIS CARD CORRESPONDS WITH THE INPUT CARD NO. 1 OF THE NEXT DATA SET.
B2 Program Listing

This section provides a complete listing of the Roskam/Fillman Program.
1 DIMENSION LCOD(500),L(500),SVL(500),SHL(500),LCOD(1),LO(1),LCOD(1)
2 *SCOD(500),SV(1),JVD(1),SHU(1),SDH(1),SUPV(1),SWPVL(1),SWF(1),SWETF(1)
3 *SWET(1),SWETN(1),SWEO(1),SWEO(1),WAITF(1),WUTC(1),WFU(1),LW(1),WC(1)
4 *SCOD(500),SV(1),JVD(1),SHU(1),SDH(1),SUPV(1),SWPVL(1),SWF(1),SWETF(1)
5 *SCOD(500),SV(1),JVD(1),SHU(1),SDH(1),SUPV(1),SWPVL(1),SWF(1),SWETF(1)
6 *SCOD(500),SV(1),JVD(1),SHU(1),SDH(1),SUPV(1),SWPVL(1),SWF(1),SWETF(1)
7 *LABEL3(14),ARCRFT(13)
8 DIMENSION XB(500),XBD(500),XBD(500)
9 COMMON TAS,AMACH,VISCOS,SW,BW,AW,SW,CBAR,SWPC,SWPVL,SWF,SWETFO,SWETB,SWETF(1)
10 *SWETFO(1),SWETB(1),SWETF(1),SWETB(1),SWETF(1),SWETB(1),SWETF(1),SWETB(1),SWETF(1)
11 *SWETFO(1),SWETB(1),SWETF(1),SWETB(1),SWETF(1),SWETB(1),SWETF(1)
12 *SUPO,SWPVL,SWPVL,SWPVL,SWPVL,SWPVL,SWPVL,SWPVL,SWPVL,SWPVL
13 4ULTC(1),DTC(1,1)
14 5C(1),C(1),C(1),C(1),C(1),C(1),C(1),C(1),C(1),C(1),C(1)
15 COMMON/STAB/XBAR,XXBAR,XXBAR,XXBAR,XXBAR
16 COMMON/RHO/DENSIT
CALL XBARCG(0,XBCG)
SMFW = SWPLE + 57.3
WRITE(6,5)TEST,ARCRFT
WRITE(6,6)ALT,ASA,AMACH,DENS,THICK,T,AMACH
WRITE(6,7)SH,AW,AV,CBAR,XCBAR,SMFW,TAPRW
WRITE(6,8)LBWD,LNW,LU,LW,LCOLO,FUSINO,FUSHT,DFUS
WRITE(6,9)SHO,BOH,AN,CHI,TAPR,TAPR,THICKU
WRITE(6,10)SVO,VW,AV,CVO,TAPRV,THICKV
WRITE(6,11)ALO,AVO,CH,SWPW,TAPRW
WRITE(6,12)TEST,ARCRFT
WRITE(6,13)WGR0SS
WRITE(6,14)TEST,ARCRFT
WRITE(6,15)SWETNO,SWETUO,SWETCO,SWETO,SWETF,SWETE,SWETN
WRITE(6,16)SWPH,SWPV,SWF,SWU,SWC,SWFW,SWV,WE
WRITE(6,17)SVO,BVO,AV,CVO,TAPRV,THICKV
WRITE(6,18)SHO,BHO,CH,SWPH,SWPV,SWF,SWU,SWC,SWFW,SWV,WE
WRITE(6,19)lb,lb,LUM,LC1
DO 100 I=1,100
LC2 = LC1 + ((I-1)·DLA)
LBME = LN+LU+LC2
DELTLC = LC2-LC0
CALL SWET(PHINT,PHIC1,SH,SV,LC2,SWETU,SWETU,SWETU,SWETH,SWETH,SWETU,SWETH,SWETH)
CALL SWET(PHINT,PHIC1,SH,SV,LC2,SWETU,SWETU,SWETU,SWETH,SWETH,SWETU,SWETH,SWETH)
CALL SWET(PHINT,PHIC1,SH,SV,LC2,SWETU,SWETU,SWETU,SWETH,SWETH,SWETU,SWETH,SWETH)
CALL SWET(PHINT,PHIC1,SH,SV,LC2,SWETU,SWETU,SWETU,SWETH,SWETH,SWETU,SWETH,SWETH)
CALL XOARCG(I,XBCG)
SWEFT = SWEFN + SWEU + SWEIC
SWEFE = SWEFT + SWEF
CALL COOLNEWS, VSPL, HSWPL, SWEF, SWEIE, SWEFT, SWF, CH, CV, COOBHV)
SWW(I) = SWF
SWH(I) = SWEF
SWT(I) = SWEFT + SWEFE
LCOD(I) = LC2DFUS
L(I) = LC2
XSW(I) = XBARW
XBB(I) = XACCD
XBN(I) = XBARH
XBA(I) = XBARAC
SLCL(I) = SV
SHL(I) = SH
CDOL(I) = COOBHV
BNL(I) = BV
BNH(I) = BH
SWPL(I) = VSPL + 57.3
SWPVL(I) = VSPL + 57.3
SWF(I) = SWEFT
SWE(I) = SWEFE
SWC(I) = SWEIC
SWN(I) = SWEFT
WAIT(I) = WGR + WC
WAITE(I) = WEMP
LBL(I) = LBNW
XCGL(I) = XBCG
CBV(I) = CV
CBV(I) = CV
CONTINUE
WRITE (6,16) TEST, ARCRAFT, WGR, ((L(I), LBL(I), WAITF(I), WAITE(I)),
XCGL(I)) = (1, IF)
WRITE (6,17) TEST, ARCRAFT, CH, AV, TAPRY
WRITE (6,18) ((L(I), SHL(I), BNL(I), CBN(I), SWPL(I)), I = 1, IF)
CALL M15A(2, L, SHL, IF, LO, SHO, L, LABEL2)
WRITE (6,19) TEST, ARCRAFT, CHN, AV, TAPV
WRITE (6,10) ((L(I), SVL(I), BVL(I), CBN(I), SWPVL(I)), I = 1, IF)
CALL M15A(2, L, SVL, IF, LO, SVO, L, LABEL3)
WRITE (6,21) TEST, ARCRAFT, CHA
WRITE (6,22) ((L(I), XBM(I), XBR(I), XBN(I), XBA(I), XA(I), XCGL(I)),
*I = 1, IF)
WRITE (6,23) TEST, ARCRAFT
WRITE (6,24) ((L(I), SF(I), SW(I), SHVC(I), SWT(I)), I = 1, IF)
WRITE (6,25) TEST, ARCRAFT, COG(I)
WRITE (6,26) ((L(I), LCOD(I), LCOD(I), COG(I), T, LABEL1)
CALL M15A(2, LCOD, COG, IF, LCOD, COG, T, LABEL1)
GOTO 10
1 FORMAT(13A6, A2)
2 FORMAT(7F13.0)
3 FORMAT(4I2)
<table>
<thead>
<tr>
<th>Line</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>156</td>
<td>FORMAT(3F10.0,1X,13)</td>
</tr>
<tr>
<td>157</td>
<td>5 FORMAT(1H1,1D4,1A6,'1A ROSKAM-FILLMAN METHOD'//27X,12A6,</td>
</tr>
<tr>
<td>158</td>
<td>*A2/27X,'ORIGINAL FLIGHT CONDITIONS AND'//27X,'GEOMETRIC DEFINITIONS</td>
</tr>
<tr>
<td>159</td>
<td><em>]'/10X,65C('</em>)//</td>
</tr>
<tr>
<td>160</td>
<td>6 FORMAT(10X,'FLIGHT CONDITIONS'//15X,'ALTITUDE',T5Q,F10.3,' FT'//</td>
</tr>
<tr>
<td>161</td>
<td>*/15X,'AIRSPEED',T5Q,F10.3,' FPS'//15X,'MACH',T5Q,F10.3,15X,'DENSITY</td>
</tr>
<tr>
<td>162</td>
<td>*]'5Q,F10.5,' SLUGS/CU.FT.'//15X,'KINEMATIC VISCOITY',T5Q,F10.5,</td>
</tr>
<tr>
<td>163</td>
<td>*]'50, FT./SEC//'</td>
</tr>
<tr>
<td>164</td>
<td>7 FORMAT(10X,'GEOMETRIC'//15X,'WING'//20X,'REFERENCE AREA',T5Q,F10.3,</td>
</tr>
<tr>
<td>165</td>
<td>*]'5D,F10.3,' FT'//20X,'SPAN',T5Q,F10.3,' FT'//20X,'ASPECT RATIO',T5Q,F10.3,</td>
</tr>
<tr>
<td>166</td>
<td>*]'20X,'M.A.C.',T5Q,F10.3,' FT'//20X,'MAX WIND',T5Q,F10.3,' FT'//</td>
</tr>
<tr>
<td>167</td>
<td>*]'Sweep',T5Q,F10.3,' DEG'//20X,'TAPER',T5Q,F10.3//</td>
</tr>
<tr>
<td>168</td>
<td>8 FORMAT(15X,'FUSELAGE'//20X,'OVERALL LENGTH',T5Q,F10.3,' FT'//20X,</td>
</tr>
<tr>
<td>169</td>
<td>*]'50, FT.'//20X,'SPAN',T5Q,F10.3,' FT'//20X,'CABIN LENGTH',T5Q,F10.3,</td>
</tr>
<tr>
<td>170</td>
<td>*]'20X,'TAIL CONE LENGTH',T5Q,F10.3,' FT'//20X,'MAX WIND',T5Q,F10.3,</td>
</tr>
<tr>
<td>171</td>
<td>*]'FT'//20X,'MAX HEIGHT',T5Q,F10.3,' FT'//20X,'EQUIV. DIAMETER',T5Q,</td>
</tr>
<tr>
<td>172</td>
<td>*]'FT'//</td>
</tr>
<tr>
<td>173</td>
<td>9 FORMAT(15X,'HORIZONTAL TAIL'//20X,'REFERENCE AREA',T5Q,F10.3,</td>
</tr>
<tr>
<td>174</td>
<td>*]'50, FT.'//20X,'SPAN',T5Q,F10.3,' FT'//20X,'ASPECT RATIO',T5Q,F10.3,</td>
</tr>
<tr>
<td>175</td>
<td>*]'20X,'M.A.C.',T5Q,F10.3,' FT'//20X,'TAPER',T5Q,F10.3//</td>
</tr>
<tr>
<td>176</td>
<td>10 FORMAT(15X,'VERTICAL TAIL'//20X,'REFERENCE AREA',T5Q,F10.3,</td>
</tr>
<tr>
<td>177</td>
<td>*]'50, FT.'//20X,'SPAN',T5Q,F10.3,' FT'//20X,'ASPECT RATIO',T5Q,F10.3,</td>
</tr>
<tr>
<td>178</td>
<td>*]'20X,'M.A.C.',T5Q,F10.3,' FT'//20X,'TAPER',T5Q,F10.3//</td>
</tr>
<tr>
<td>179</td>
<td>11 FORMAT(1H1,10X,'TABLE ',A6,' ROSKAM-FILLMAN METHOD'//27X,12A6,</td>
</tr>
<tr>
<td>180</td>
<td><em>A2/27X,'ORIGINAL WEIGHT AND BALANCE STATEMENT'//10X,65C('</em>)//</td>
</tr>
<tr>
<td>181</td>
<td>*]'52,'(LBS.)'//110X,'GROSS WEIGHT',T55,'(LBS.)'</td>
</tr>
<tr>
<td>182</td>
<td>12 FORMAT(10X,'APPROXIMATED SHELL WEIGHTS', //15X,</td>
</tr>
<tr>
<td>183</td>
<td>*]'5Q, FT.'//20X,'SPAN',T5Q,F10.3,' FT'//20X,'CABIN SECTION',T5Q,F10.3,</td>
</tr>
<tr>
<td>184</td>
<td>*]'20X,'M.A.C.',T5Q,F10.3,' FT'//20X,'TAPER',T5Q,F10.3//</td>
</tr>
<tr>
<td>185</td>
<td>13 FORMAT(10X,'APPARENT SHELL WEIGHTS', //15X,</td>
</tr>
<tr>
<td>186</td>
<td>*]'5Q, FT.'//20X,'SPAN',T5Q,F10.3,' FT'//20X,'CABIN SECTION',T5Q,F10.3,</td>
</tr>
<tr>
<td>187</td>
<td>*]'20X,'M.A.C.',T5Q,F10.3,' FT'//20X,'TAPER',T5Q,F10.3//</td>
</tr>
<tr>
<td>188</td>
<td>14 FORMAT(1H1,10X,'TABLE ',A6,'1C ROSKAM-FILLMAN METHOD'//27X,12A6,</td>
</tr>
<tr>
<td>189</td>
<td><em>A2/27X,'ORIGINAL NETTED AREA BREAKDOWN'//10X,65C('</em>)//</td>
</tr>
<tr>
<td>190</td>
<td>15 FORMAT(10X,'FUSELAGE'//15X,'NOSE SECTION',T5Q,F10.3,</td>
</tr>
<tr>
<td>191</td>
<td>*]'15X,'CABIN SECTION',T5Q,F10.3,' TAIL SECTION',T5Q,F10.3,</td>
</tr>
<tr>
<td>192</td>
<td>16 FORMAT(1H1,10X,'TABLE ',A6,'2A ROSKAM-FILLMAN METHOD'//27X,12A6,</td>
</tr>
<tr>
<td>193</td>
<td>*A2/27X,'OPTIMIZATION STABILIZER'//27X,'SIZING'//27X,'CHA = ',T55,</td>
</tr>
<tr>
<td>194</td>
<td><em>]'10X,65C('</em>)//</td>
</tr>
<tr>
<td>195</td>
<td>17 FORMAT(1H1,10X,'TABLE ',A6,'2B ROSKAM-FILLMAN METHOD'//27X,12A6,</td>
</tr>
<tr>
<td>196</td>
<td>*A2/27X,'OPTIMIZATION STABILIZER'//27X,'SIZING'//27X,'CHA = ',T55,</td>
</tr>
<tr>
<td>197</td>
<td><em>]'10X,65C('</em>)//</td>
</tr>
</tbody>
</table>
208 18 FORMAT((10X,'A6','A3','X'))
209 19 FORMAT((10X,'A6','A3','X'))
210 20 FORMAT((10X,'A6','A3','X'))
211 21 FORMAT((10X,'A6','A3','X'))
212 22 FORMAT((10X,'A6','A3','X'))
213 23 FORMAT((10X,'A6','A3','X'))
214 24 FORMAT((10X,'A6','A3','X'))
215 25 FORMAT((10X,'A6','A3','X'))
216 26 FORMAT((10X,'A6','A3','X'))
217 27 FORMAT((10X,'A6','A3','X'))
218 28 FORMAT((10X,'A6','A3','X'))
219 29 FORMAT((10X,'A6','A3','X'))
220 30 FORMAT((10X,'A6','A3','X'))
221 31 FORMAT((10X,'A6','A3','X'))
222 32 FORMAT((10X,'A6','A3','X'))
223 33 FORMAT((10X,'A6','A3','X'))
224 34 FORMAT((10X,'A6','A3','X'))
225 35 FORMAT((10X,'A6','A3','X'))
226 36 FORMAT((10X,'A6','A3','X'))
227 37 FORMAT((10X,'A6','A3','X'))
228 38 FORMAT((10X,'A6','A3','X'))
229 39 FORMAT((10X,'A6','A3','X'))
230 40 FORMAT((10X,'A6','A3','X'))
231 41 FORMAT((10X,'A6','A3','X'))
232 42 FORMAT((10X,'A6','A3','X'))
233 43 FORMAT((10X,'A6','A3','X'))

*1470 EQUALITY OR NON-EQUALITY COMPARISON MAY NOT BE MEANINGFUL IN LOGICAL IF EXPRESSIONS
SUBROUTINE SWET (PHI1, PHI2, SH, SV, TALGT, SWETN, SWETU, SWETV)

COMMON TAS, MACH, VISCOS, SW, AW, CDAR, WSPLT, TAPRH, XBAR, LBD, 
1FUS, NOSLGT, CALGT, LOLD, FUSID, FUSHT, M1, H2, PHI1, PHI2, PHI2I

PHI2, TOL,

2K1, K2, K3, K4, SHO, BHO, AH, WPHO, TAPRH, THICKH, LHD, HH, SVO, BVO, AV,

3SVPO, TAPRV, THICKV, LVOLD, AEFF, K1, KEMP1, KEMP2, SBSN, SBSU, SBSI, DIVE,

4ULTLOAD, XCG, XCGH, XCGV, XBAR1, XBAR2, XBAR3, XGHA, XGHB, XGVC,

5KAPAW, KAPA, KAPAV,

6ETA, DELTLC, EP

REAL KW, KV, KC, KA, NOSLGT

DATA PI/3.14159/ 

CIRCUM = DFUS * PI

SWETU = CIRCUM * CALGT

SWETN = CIRCUM * NOSLGT * KW

CALL CONPAR (PHI1, KA, KV, KC, KW)

SWETC = CIRCUM * TALGT * KW

CKP = .52 * THICKH + 1.987

CKP = .52 * THICKV + 1.987

SWETH = CKP * SH

SWETV = CKP * SV

RETURN

END
SUBROUTINE COO (ALQ, SWPV, SWPH, SWET, SWETV, SWETF, CBARH, CBARV)

1CDQBHV)

COMMON TAS, AMACH, VISCOS, SW, DFW, CBAR, $WPVI, TAPRV, $BARH, LBOLD

1DUS. LN, LCLDOL, FUSWD, FUSHT, H2PHT1, PHN2, PHIC1, PHIC2, TOL

2K1, K2, K3, K4, SQO, BDO, AH, $PH0, TAPRH, THICKH, LHOLO, HH, SVG, BVO, AV

3$WPV, TAPRV, THICKH, LHOLO, AEF, $K, KEMPI, KEMP2, SUBH, SBSL, SBS1, DIVE

4$ULTO, XOR, XCGV, XBARH, XBARH0, CHA, CHB, KAPAH, KAPAH, KAPAV

5RENUNF = RENUM (DENSIT, VISCOS, TAS, ALB)

6CFMO = 0.455 / (ALOG10 (RENNUM) + 2.58)

7CFCH = 6.899 * AMACH - 16.226 * AMACH**2 + 15.741 * AMACH**3 - 5.4894 * AMACH + 4

8SKIN = CFMO * CFCH

9IF (AMACH.LT.0.25) GOTO 650

10RLIFT = Y - 16.12 * SWPH + 33.15 * SWPH**2 - 27.82 * SWPH**3 + 8.32 * SWPH**4

11GOTO 660

12IFAMACH.LT.0.25) GOTO 670

13RLIFT = 3.541 - 16.12 * SWPH + 33.15 * SWPH**2 - 27.82 * SWPH**3 + 8.32 * SWPH**4

14GOTO 660

15DOH = $SKIN * $WPV / SWPH

16CDOH = $SKIN * $WPV / SWPH

17CDOHT = $SKIN * $WPV / SWPH

18CDOHV = CDOHV + CDOHT + CDOV

19RETURN

20END
SUBROUTINE FUSWGT(SWETF,SWETH,SWETU,SWETC,WF,WN,WU,WC)

COMMON TAS,AMACH,VISCO2,SM,AW,CBAR,WSHPL,E,TAPRH,XI,GBAR,LOLD,E
1DFUS,LN,LU,LOLD,FUSWD,FUSHT,H,PH,H2,PH1,PH2,PHIC1,PHIC2,TOL,E
2K1,K2,K3,K4,SHO,DHO,AM,SWPHO,TAPRH,THICK,LHOLD,HH,SV,DO,AV,E
3SNPOG,TARP,H,THICKV,LOLD,AEFF,K,KEMP1,KEMP2,SUSN,SBUS,SBSC1,DIVE,E
4ULoad,XG,XCM,XCGV,XBARH,PHCM,CHB,KAPAH,KAPAH,KAPAH,KAPAH
5SEF,DELLC,EP

REAL LHOLD

C THIS SUBROUTINE, FUSWGT, ESTIMATES THE FUSELAGE WEIGHT WHEN THE
C DIVE SPEED, WETTED AREA, FUSELAGE GEOMETRY, AND FOUR CORRECTION
C FACTORS TO ACCOUNT FOR PRESSURIZATION, ENGINE LOCATION, AND
C LANDING GEAR LOCATION ARE KNOWN.

C DETERMINATION OF FUSELAGE CORRECTION FACTORS FROM OPTIONCODES

10 IF(K1-1)110,120,130
11 FUSK1=1.08
12 GO TO 140
13 FUSK1=1.00
14 IF(K2-1)160,150,160
15 FUSK2=1.04
16 GO TO 170
17 FUSK2=1.0
18 IF(K3-1)190,180,190
19 FUSK3=1.07
20 GO TO 200
21 FUSK3=1.0
22 IF(K4-1)220,210,220
23 FUSK4=0.96
24 GO TO 230
25 FUSK4=1.0

C FROM THE INPUT DATA AND THE FUSELAGE CORRECTION FACTORS, THE
C ESTIMATED FUSELAGE WEIGHT CAN BE COMPUTED

38 IF(K-1)230,240,250
39 FUSK = FUSK1+FUSK2+FUSK3+FUSK4
40 OCWHT = LHOLD + DELTLC
41 A = DIVE + OCWHT
42 B = FUSWD + FUSHT
43 C = A/B
44 D = SWETF*1.2
45 E = SQRT(C)
46 WF = 0.021+FUSK+B/E
47 WN = AFUSK/AFUSK
48 WU = AFUSK + SWETF
49 WC = AFUSK + SWETC
50 RETURN
51 END
SUBROUTINE EMPWGT(SWETH,SWETV,SWET,EHTARE,HSPAN,VTARE,VTSPAN,
*SWPLE,VSPLE,VTWGHT,HTWGHT,EMPWGH)

COMMON TAS,AMACH,VISCOS,SW,SWN,SWAN,SWBAR,VSPL,E,VTAR,HTAR,
1FUS,LN,LM,LO,LCD,ULFUS,IDT,PHI1,PHI2,TOL,
2K1,K2,K3,K4,SH,DH,AH,SV,SP,THK,H,NH,SV0,SV1,AV,
3SWPVG,TPRG,Thick,LV0L,SBF,K,KEFP1,KEFP2,SBS,SBSU,SBC1,DIVE,
4ULTLOAD,XCG,XCHG,XBARMB,XBARKO,XBARO,HT,CMB,CMAP,KAPA,KAPAV,
5SETA,TBL,EQ

THIS SUBROUTINE EMPWGT, CALCULATES THE ESTIMATED WEIGHT OF AN 
EMPENNAGE WHEN THE DIVE SPEED, WETTED AREA, AND EMPENNAGE 
GEOMETRY ARE KNOWN - - -

EMPENNAGE WEIGHT FOR DIVE SPEED LESS THAN 250 KTS
IF(DIVE.GT.250)GOTO500
EMPWGH=.**(ULTLOAD*SWET+f2)**.75
HTWGHT = EMPWGH+SWETV/SPET
GOTO 630

EMPENNAGE WEIGHT WHEN DIVE SPEED GREATER THAN 2V0 KTS

DETERMINATION OF EMPENNAGE CORRECTION FACTORS
500 IF(KEMP1-1)530,520,530
520 EMPH1=1.1
GOTO5Q0
530 IF(KEMP2-1)560,550,560
550 EMPK2=1.+1.5*(HHTAREA/HSPAN/VTAREA/VTSPAN)
GOTO570
560 EMPK2=1.

DETERMINATION OF HORIZONTAL AND VERTICAL TAIL CORRECTION FACTORS
570 HHTCF=HHTAREA**.2*DIVE/1000./SRT(COS(HSPL))
VTCF=VTAREA**.2*DIVE/1000./SRT(COS(VSPL))
IF(HHTCF.GT.1.40)GOTO580
HTWGHT=(2.06-4.05)*HHTAREA*EMPWH1
GOTO590
580 HHTWGHT=(2.06-4.05)*ALOG(HHTCF)*HHTAREA*EMPK2
590 IF(VTCF.GT.1.40)GOTO600
VTWGHT=(3.9*VTCF**.419)*VTAREA*EMPK
600 VTTWGHT=(2.06-4.05)*ALOG(VTARCF)*VTAREA*EMPK
GOTO610
610 EMPWGH = HTWGHT + VTWGHT
630 CONTINUE
650 RETURN
END
THIS SUBROUTINE ESTIMATES THE LOCATION OF THE C.G. OF THE AIRCRAFT ALONG THE LONGITUDINAL AXIS. THE METHOD USED IS NOT INTENDED TO ACCURATELY LOCATE THE C.G., BUT RATHER TO AID IN LOCATING THE C.G. SHIFT DUE TO INCREMENTALLY LENGTHENING THE AIRCRAFT TAIL CONE.

INPUTS REQUIRED FOR THIS SUBROUTINE ARE LISTED BELOW AND MUST BE ENTERED INTO THE SUBROUTINE THROUGH EITHER READ STATEMENTS OR COMMON.

- NOSE LENGTH (FT)
- CABIN LENGTH (FT)
- TAIL CONE LENGTH (FT)
- FUSELAGE WEIGHT (LB)
- EMPENNAGE WEIGHT (LB)
- NOSE CONE SHAPE PARAMETERS
- TAIL CONE SHAPE PARAMETERS
- VERT. TAIL C.G. LOCATION (FT)
- TAIL CONE INCREMENT NUMBER

REAL M,N,LN,LU,LN,MN,NN,NC,LC,LCLD
X(M+1,N) = (1.0-(M+1.0)/(M+1.0))/((M+1.0)/(M+1.0))

CALL CONSHP(PHN1,PHN2,TO1,MN,NN)
CALL CONSHP(PHIC1,PHIC2,MC,NC)
X = X(LC,MC,NC) + LN + LU
ARM1 = WGR + XCG + MC + XC

CALL CONSHP(PHNC1,PHNC2,MC,NC)
X5 = XCGV + DELTLC
KH = XCGH + DELTLC
ARM2 = WH*XH + WH*XV
53
54 C ESTIMATE AIRCRAFT C.G. LOCATION
55 C
56 WEST = WGR + WC + WH + WV
57 XCGEST = (ARM1 + ARM2)/WEST
58 IF(I.GT.0) GO TO 100
59 C COMPUTE CORRECTION FACTOR -- CGERR
60 C
61 CGERR = (XCG - XCGEST)
62 XCG1 = XCG
63 GO TO 200
64 100 XCG1 = XCGEST + CGERR
65 200 XBCG = (XCG1 - XCBAR)/CBAR
66 RETURN
67 END
SUBROUTINE STABAREA(XBARCG, HSWPLE, SH, BH, CH)

COMMON/STAB/XBARW, XBARAC, XACBB, XBARH

COMMON/AMACH, VISCOS, SW, AW, CBAR, HSWPLE, TAPRH, XBARH, LOLD

LORD=SUM(XBARW, XBARAC, XACBB, XBARH)

COMMON/TAS, AMACH, VISCOS, SW, AW, CBAR, HSWPLE, TAPRH, XBARH, LOLD

1DFUS (N, L0, LOLD, FUSW, FUSHG, H1, H2, PHINT, PHINT2, PHIC1, PHIC2, TOL,

2K1=2.35, VSB, SBSN, SBS, SBSU, SBS1, SBS2, TOL

3SNP=3.3, TAPRH, THICK, LHOLD, HH, SBO, SBO, AV

4LOAD=XCG, XCH, XCGV, XBARWB, XBARHC, MA, CNB, KAPA, KAPA, KAPA, KAPA

5SH=SHP

6SH=SHP

7HSWPLE=SWPHO

8SH=SHP

9SH=SHP

10SH=SHP

11SHP

12SH=SHP

13SH=SHP

14SH=SHP

15SH=SHP

16SH=SHP

17SH=SHP

18SH=SHP

19SH=SHP

20SH=SHP

21SH=SHP

22SH=SHP

23SH=SHP

24SH=SHP

25SH=SHP

26SH=SHP

27SH=SHP

28SH=SHP

29SH=SHP

30SH=SHP

31SH=SHP

32SH=SHP

33SH=SHP

34SH=SHP

35SH=SHP

36SH=SHP

37SH=SHP

38SH=SHP

39SH=SHP

40SH=SHP

41SH=SHP

42SH=SHP

43SH=SHP

44SH=SHP

45SH=SHP

46SH=SHP

47SH=SHP

48SH=SHP

49SH=SHP

50SH=SHP

51SH=SHP

52CALL LSLOPE (SLOPE)
53 CLAH=SLOPE
54 C
55 C NOW WE COMPUTE XBARACH
56 C
57 XBAR掀=XBAR掀+DELTL/CBAR+(((BH/BW)+(1.*2.*TAPRH)/(1.+TAPRH))*(SIN(HSWP2)/COS(HSWP2))-(SIN(HSWP2)/COS(HSWP2))/CBAR
58 C
59 C NOW WE CALCULATE D EPSILON / D ALPHA
60 C
61 C
62 C ASPECT =AW
63 C SWPC2=ASAIPC2
64 DATA=BETA
65 KAPPA=KAPA
66 CALL LSLOPE (SLOPE)
67 CLAW=SLOPE
68 DATA=1.
69 CALL LSLOPE (SLOPE)
70 CLAW=SLOPE
71 KA=1./(AW)~(1./(1.+AW*x1.7))
72 KTAPR=(10.-((3.*TAPRH)))/7.
73 KH=1./((HI/BW))/((2.*LHNEW)/BW)**.3333
74 DEPDAL=(CLAW*CLAW)*((.4.*(KA*KTAPR*KH*SQRT(COS(HSWP2))))**1.19)
75 C
76 C NEXT COMPUTE CL ALPHA WB
77 C
78 KWB = 1.-((.25*(DFUS/BW)**2)+.025*DFUS/BW)
79 CLAWB=KWB*CLAW
80 C
81 C NEXT COMPUTE THE TOTAL AIRPLANE CL' ALPHA
82 C
83 CLAA=CLAW+CLAH*ETA/SW*(1.-DEPDAL)
84 C
85 C COMPUTE XBARAC
86 C
87 XBARAC=XBARAC-CMA/CLAA
88 CALL MULTOP(LHNEW,CLAW,DEPDAL,DXACD)
89 XBARAC=XBARAC+DXACD
90 C
91 C NOW THAT ALL PARAMETERS ARE KNOWN WE CAN COMPUTE THE NEW AREA
92 C
93 SHNEW=(XBARAC-XBARA)*((XBARAC-XBARA)*(CLAH/CLAW)*
94 *ETA/SW)*(1.-DEPDAL)
95 SHNEW=SQRT(SHNEW*AH)
96 BHDIFF=ABS(BHNEW-BH)
97 IF (BHDIFF.LT.EP) GO TO 3C
98 SH=SHNEW
99 BH=BHNEW
100 GO TO 1
101 C
102 C
103 C
104 C
H$\text{W}$P$L = \text{ATAN} \left( \frac{\text{SIN}(H\text{SWP1})}{\text{COS}(H\text{SWP1})} \right) - (4. / \text{AH} \times ( - 5 \times (1. - \text{TAPRH}) /$

106\quad \times (1. \times \text{TAPRH}))\right)

107\quad \text{SWP} = \text{H$\text{W}$P$L} \times 57.3

108\quad \text{RETURN}

109\quad \text{END}
SUBROUTINE VERTAREA(VSWP,SV.CV)  
COMMON TASPAMACH•VISCOS•SWPL•AWPCBARPWS•TAPR•WE•XCOARP•LOOLD•
                 TOL0•K1•K2•PK3•K4•S•HOPE•OP•Ali•i5•WPH0•TAPRH•THICKH•O•L•NH•SV•Or•BV•Or•AV•
                 —5•S9•SUp•SOS•E•DIVE•f•fl
                 ETA•DELTA•EP
                 8CC:::40•C•EGEE/XCG1
                 REAL•KPL•VOLD•LVNEW•KN•KRL•KA•LCOLD•LBOLD•LBNEW•LB2SBS
                 REAL•H1•H2•H1•H2•0-11•HWRAT•hi2•KAPPA•KAPAV•KVo•K Cs•KUi•LN
                 COMMON/ CLDATA/ASPECIPUATA•SWPC2•PKAPPA•HV=BVO
VSWPL=SWPL•O

THE FIRST PART OF THIS ROUTINE OPTIMIZES THE SWEEP ANGLE OF THE VERTICAL TAIL FIRST WE CONVERT THE INPUT VALUE OF LE SWEEP TO HALF CHORD SWEEP

VSWP0=ATAN((SI-N(VSWPL/1)/COS(VSWPLE))-(4./AV*(.5*(1.-TAPRV)/
2*(1.+TAPRV))))

8ETA=SORT(1.-AMACH**2.)

CLLV1=11.

DO 10 1=1.181-

VSWP2=VSWP1+.DPH727

ASPECT=AEFF—_ 27 BATA=BETA

SWPC2=VSWP2

CALL LSLOPE (SLOPE)

CLAV=LSLOPE

LVOLD=LVOLD-(XCG1-XCG) (Ij-

LVNEW=LVNEW+DELTLC+(((BV/3.)*(2.+Z.*TAPRV) (1.+TAPRV 
1*((SINCVSWP2)/COS(VSWP2))-(SIN(VSWPC2)/COS(VSWPCZ))))-

CLLV2=CLAVkLVNEW

IF (CLLVI.GE.CLLV2) GO TO 20-, --- ------

LLLV1 =CLLV2

VSWPI=VSWP2

10 CONTINUE -

THE FIRST PART OF THE ROUTINE COMPUTES THE NEW VERTICAL TAIL AREA AND VERTICAL TAIL SPAN FIRST WE CALCULATE K R L

LVNEW=LBOLD+DELTLC CALL COMPAR (PHIC•KAV•KCM)

VSWP2=ATAN((SINC(SWPL))/COS(SWPL)-(4./AV*(.5*(1.-TAPRV)/
2*(1.+TAPRV))

CLLV1=0.

CLLV2=CLAVkLVNEW

IF (CLLVI.GE.CLLV2) GO TO 20-, --- ------

LLLV1 =CLLV2

VSWPI=VSWP2
NOW WE CALCULATE KN BY A THREE STEP METHOD IT WAS ARRIVED AT BY APPLYING CURVFITTING TECHNIQUES TO THE CHASE AROUND CHART IN DATCOM

\[ \text{BI}=0.05875 \times \text{LB2SUS}+1.175 \]

\[ \text{CONTINUE} \]

\[ \text{YVALUE}=2.8333 \times \text{XCGL}/\text{LBNEW}-0.41667 \times \text{S:IFT1} \]

\[ \text{H1H2}=\text{SORT}((1/\text{H1})/\text{H2}) \]

\[ \text{ZVALUE}=(\text{YVALUE})/\text{M1} \]

\[ \text{HWAT}=(\text{FUSHG}+\text{FUSHID}) \]

\[ \text{M2}=(-1.05874, 0.4264) \times \text{HWAT}-3.5626 \times \text{HWAT}^2+2.10794 \times \text{HWAT}^3-1.1217 \]

\[ \text{KN}=\text{M2} \times \text{ZVALUE}+0.005 \]

\[ \text{SWPC2}=\text{VSMP1} \]

\[ \text{CALCULATION OF THE NEW PLANFORM PARAMETERS} \]

\[ \text{CLAV}=\text{SLOPE} \]

\[ \text{COMPUTATION OF THE NEW SPAN AND COMPARISON WITH THE TOLERANCE} \]

\[ \text{BVNEW}=\text{SORT}(\text{AV} \times \text{SVNEW}) \]

\[ \text{BVDIF}=\text{ABS}(\text{BVNEW}-\text{BV}) \]

\[ \text{IF } (\text{BVDIF}<0.005) \text{ GO TO 110} \]

\[ \text{SV}=\text{SVNEW} \]

\[ \text{DV}=\text{BVNEW} \]

\[ \text{GO TO 1} \]

\[ \text{CONTINUE} \]

\[ \text{SV}=\text{SVNEW} \]

\[ \text{NY}=\text{BVNEW} \]

\[ \text{CV}=(4.4 \times \text{SV})/(3.4 \times \text{BV}) \times (1.+\text{TAPRV}+\text{TAPRV}^2)/(1.+\text{TAPRV}^2) \]

\[ \text{VSMPL}=\text{ATAN}((\text{SIN}(\text{VSMP1})/\cos(\text{VSMP1}))-4./\text{AV}(-.5 \times (1.-\text{TAPRV})/(1.+\text{TAPRV}))} \]
SWP = VSMPLE * 57.3

RETURN

END
SUBROUTINE MULTOP(LHNEW, CLAWM, DEPDAL, DXACB)

COMMON/RHO/DENSIT
COMMON TAS,AMACH,VISCOS,SN,TH,AN, CBAR,WSWPLE,TAPR,W,XCBAR,LBOLD,
1DFUS, LN, LOLD, FUSW, FUSGT, H1, H2, PHIN1, PHIN2, PHIC1, PHIC2, TOL,
2KJ, X2, X3, X4, SHO, BHO, AD, SWHO, TAPRH, THICK, LOLD, HH, SVO, BVO, AV,
3SW, PVO, TAPRV, THICKV, VOLTD, AEFF, K1, KEMP1, KEMP2, SBSN, SBSU, SHC1, D1,
4UL, LOAD, XG, XGCH, XGVR, XBARW, XBARH, CNA, CBAR, KAPAV, KAPAH, KAPA,
5SETA, DEL LC, EP

COMMON/HAPE/NN, NC, NC
DATA CO,C1,C2,C3,C4 /1.90, -1.6958, 1.5759, -0.7292, 0.13021
DATA DO,D1,D2,D3,D4 /0.2503, -0.230908, 0.603553, -0.754540, 0.302895/

POLY(X/C0,C1,C2,C3,C4)=C1*X+C2*X**2+C3*X**3+C4*X**4.

CALL = CALL/57.2958
QBAR = 0.5*DENSIT*TAS*TAS
XLE=XCBAR-(((BH/6.)*(1.+Z.*TAPRH)/(1.+TAPR)**2).5*DFUS)*SIN(WSWPLE)

***** 412 'BH' IS NOT DEFINED

CR = 1.5*CBAR*(1.+TAPR)/2*(1.+TAPR)**2)
CRF = DFUS*CR*(TAPR-1.)/BW + CR
DXI = XLE/50.

SUM = 0.
DO 100 I=1,50
X1 = XLE - (DXI*0.5) - DXI*(I-1)
IF(X1.LE.(XLE-LN)) GO TO 10
WFI = DFUS*(1.-((LN+XI-XLE)/LN)**NN)**(1./MN))**((1./MN))
GO TO 20

10 WFI = DFUS

10 WFI = DFUS

10 XCF = XI/CRF

DED = POLY(XCF,CO,C1,C2,C3,C4)
IF((XLE,45) DEDA = POLY(XCF,DO,D1,D2,D3,D4)
DEDAI = DEDA*CLAWM/4.58
100 SUM = SUM + (DXI*WFI*WFI*DEDAI)

LT = LOLD + DELTC - XLE - CRF
DXI = LT/50.
LCNEW = LOLD + DELTC
GO :50 I=1,50
X1 = DXI*(I-1)+(0.5*DXI)
IF(X1.LE.(LT-LCNEW)) GO TO 30
WFI = DFUS*(1.-((LCNEW+XI-LT)/LCNEW)**NC)**(1./MC))
GO TO 40

30 WFI = DFUS

40 LH = LHNEW-CRF+.25*CBAR+((BH/6.)*(1.+TAPR)/(1.+TAPR)-DFUS/2.)

*1/SIN(WSWPLE)/COS(WSWPLE)
DEDAI = (1.-DEPDAL)*XI/LH

200 SUM = SUM + (DXI*WFI*WFI*DEDAI)
DMDA = QBAR/36.5+SUN

DXACB = 1./DMDA/(QBAR*CBAR*SUN*CLAWM)

RETURN

END
SUBROUTINE CONSHP(PHI1, PHI2, TOL, M, N)

REAL M, N, PHI1, PHI2, M1, M2

I = 1
J = 1

N = 1.0

DM2 = 10.0

10 M1 = ALOG(1.0 - (PHI1**N))/ALOG(PHI1)
    M2 = ALOG(1.0 - (PHI2**N))/ALOG(PHI2/2.0)

J = J + 1

IF(J.EQ.100) GO TO 80

DM1 = M1 - M2

IF(DM1.LE.0.) GO TO 30

IF(DM1.LT.DM2) GO TO 50

N = N + (0.05/1)

15 DM2 = DM1

GO TO 10

17 30 IF(ABS(DM1).LT.TOL)GO TO 60

I = I + 5

18 60 N = N - (0.05/1)

20 M1 = ALOG(1.0 - (PHI1**N))/ALOG(PHI1)
    M2 = ALOG(1.0 - (PHI2**N))/ALOG(PHI2/2.0)

22 J = J + 1

23 IF(J.EQ.100) GO TO 80

24 DM1 = M2 - M1

25 IF(DM1.LT.0.) GO TO 20

26 IF(ABS(DM1).LT.TOL) GO TO 60

GO TO 40

27 50 WRITE(6,1)

28 M = 1.0

29 N = 1.0

30 GO TO 70

32 60 M = (M1 + M2)*0.5

33 70 RETURN

34 80 WRITE(6,4)

35 GO TO 60

36 1 FORMAT(10X, '****ITERATION FOR M AND N DIVERGES***'//15X, 'SET M=1.0

37 X'/22X,N=1.0'//)

38 4 FORMAT(10X, '****100 STEPS COMPLETE--DID NOT CONVERGE***'//)

39 RETURN

***** 209 STATEMENT CANNOT BE REACHED

END
SUBROUTINE CONPAR(PHI, KA, KV, KC, KW)

REAL KA, KV, KC, KW

C THIS SUBROUTINE COMPUTES THE AREA CORRECTION FACTORS KA, KV, KC, AND KW WHEN THE SHAPE PARAMETER PHI IS INPUTTED

C THIS SUBROUTINE WAS DERIVED FROM TORENOECK PG. 447

C

DATA AK,AK1,AK2,AK3,AK4/-0.59,5.8109,5.721,6.4163,-2.9167/

DATA VK,VK1,VK2,VK3,VK4/-9.095,5.803,13.0927,16.5927,-7.4074/

DATA CK,CK1,CK2,CK3,CK4/2.96,-12.0488,22.8752,-18.3333,5.5556/

DATA WK,WK1,WK2,WK3,WK4/-172.721,1008.8388,-2162.25,2023.9877,-69.7907/

C

POLY(X,C1,C2,C3,C4)=C1+X+C2*X**2.+C3*X**3.+C4*X**4.

KA=POLY(PHI,AK,AK1,AK2,AK3,AK4)

KV=POLY(PHI,VK,VK1,VK2,VK3,VK4)

KC=POLY(PHI,CK,CK1,CK2,CK3,CK4)

KW=POLY(PHI,WK,WK1,WK2,WK3,WK4)

CONTINUE

RETURN

END
SUBROUTINE LSLOPE (SLOPE)
REAL KAPPA
COMMON /CLDBATA/ASPECT,DATA,SWPC2,KAPPA
SLOPE=(2.*3.14159*ASPECT)/(2.*SQRT((ASPECT**2.*DATA**2./KAPPA**2.+
*+4.)))
RETURN
END
FUNCTION RENUM(DENSIT, VISCOS, TAS, ALNGTH)

C THIS FUNCTION COMPUTES THE REYNOLDS NUMBER OF A BODY

C RENUM=(TAS*ALNGTH)/VISCOS

RETURN

END
B3 Example Output

This section provides Roskam/Fillman Program output for a conceptual aircraft configuration. This conceptual aircraft is not to be confused with any of those mentioned in Chapter 4.
## Table 2.15.1A ROSKAM-FILLMA14 Method

**Configuration J (31 Pax, 2/2)**

### Original Flight Conditions and Geometric Definitions

<table>
<thead>
<tr>
<th>Flight Conditions</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude</td>
<td>25000.000 FT</td>
</tr>
<tr>
<td>Airspeed</td>
<td>366.750 FPS</td>
</tr>
<tr>
<td>Mach</td>
<td>0.361</td>
</tr>
<tr>
<td>Density</td>
<td>0.00107 SLUGS/CU.FT.</td>
</tr>
<tr>
<td>Kinematic Viscosity</td>
<td>0.00030 SQ.FT./SEC</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Geometric Definitions</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing Reference Area</td>
<td>440.000 SQ.FT.</td>
</tr>
<tr>
<td>Span</td>
<td>66.330 FT</td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td>10.000</td>
</tr>
<tr>
<td>M.A.C.</td>
<td>6.880 FT</td>
</tr>
<tr>
<td>F.S.</td>
<td>19.840 FT</td>
</tr>
<tr>
<td>L.E. Sweep</td>
<td>0.500 DEG</td>
</tr>
<tr>
<td>Taper</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fuselage</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Length</td>
<td>56.350 FT</td>
</tr>
<tr>
<td>Nose Length</td>
<td>14.620 FT</td>
</tr>
<tr>
<td>Cabin Length</td>
<td>20.000 FT</td>
</tr>
<tr>
<td>Tail Cone Length</td>
<td>21.760 FT</td>
</tr>
<tr>
<td>Max Width</td>
<td>8.080 FT</td>
</tr>
<tr>
<td>Max Height</td>
<td>8.080 FT</td>
</tr>
<tr>
<td>Equiv. Diameter</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Horizontal Tail</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Area</td>
<td>55.600SQ.FT.</td>
</tr>
<tr>
<td>Span</td>
<td>14.910 FT</td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td>4.000</td>
</tr>
<tr>
<td>M.A.C.</td>
<td>3.870 FT</td>
</tr>
<tr>
<td>Taper</td>
<td>0.500</td>
</tr>
<tr>
<td>Thickness</td>
<td>0.090</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vertical Tail</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Area</td>
<td>48.380SQ.FT.</td>
</tr>
<tr>
<td>Span</td>
<td>6.360 FT</td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td>1.000</td>
</tr>
<tr>
<td>M.A.C.</td>
<td>7.210 FT</td>
</tr>
<tr>
<td>Taper</td>
<td>0.500</td>
</tr>
<tr>
<td>Thickness</td>
<td>0.090</td>
</tr>
</tbody>
</table>
### TABLE 2.15.10 ROSKAM-FILM METHOD
**CONFIGURATION J (31 PAX, 2/2)**
**ORIGINAL WEIGHT AND BALANCE STATEMENT**

<table>
<thead>
<tr>
<th>Description</th>
<th>Weight (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gross Weight</strong></td>
<td>22000.000</td>
</tr>
<tr>
<td><strong>Approximated Shell Weights</strong></td>
<td></td>
</tr>
<tr>
<td>FUSELAGE</td>
<td></td>
</tr>
<tr>
<td>Nose Section</td>
<td>754.560</td>
</tr>
<tr>
<td>Cabin Section</td>
<td>1266.399</td>
</tr>
<tr>
<td>Tail Cone Section</td>
<td>1264.082</td>
</tr>
<tr>
<td>Total Fuselage</td>
<td>3265.040</td>
</tr>
<tr>
<td><strong>Empennage</strong></td>
<td></td>
</tr>
<tr>
<td>Horizontal Tail</td>
<td>115.226</td>
</tr>
<tr>
<td>Vertical Tail</td>
<td>330.431</td>
</tr>
<tr>
<td>Total Empennage</td>
<td>445.657</td>
</tr>
<tr>
<td>Center of Gravity -- Fraction of MAC</td>
<td>0.250</td>
</tr>
</tbody>
</table>
### TABLE 2.15.1C ROSKAM-FILLMAN METHOD

**CONFIGURATION J (31 PAX, 2/2)
ORIGINAL WETTED AREA BREAKDOWN**

<table>
<thead>
<tr>
<th>FUSELAGE</th>
<th>(SQ. FT.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOSE SECTION</td>
<td>307.346</td>
</tr>
<tr>
<td>CABIN SECTION</td>
<td>507.681</td>
</tr>
<tr>
<td>TAIL SECTION</td>
<td>514.883</td>
</tr>
<tr>
<td>TOTAL FUSELAGE</td>
<td>1329.910</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EMPENNAGE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>HORIZONTAL TAIL</td>
<td>113.079</td>
</tr>
<tr>
<td>VERTICAL TAIL</td>
<td>98.395</td>
</tr>
<tr>
<td>TOTAL EMPENNAGE</td>
<td>211.475</td>
</tr>
</tbody>
</table>
### Table 2.15.2A Roskam-Fillman Method

**Configuration J (31 Pax, 2/2)**  
**Optimization Weight and Balance Statement**

<table>
<thead>
<tr>
<th>Gross Weight (W/O Tail or Emp.)</th>
<th>20290.261 (LBS.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Weight (W/O Tail or Emp.)</td>
<td>20290.261 (LBS.)</td>
</tr>
<tr>
<td>(LB)</td>
<td>(FT)</td>
</tr>
<tr>
<td>1</td>
<td>15.000</td>
</tr>
<tr>
<td>2</td>
<td>15.250</td>
</tr>
<tr>
<td>3</td>
<td>15.500</td>
</tr>
<tr>
<td>4</td>
<td>15.750</td>
</tr>
<tr>
<td>5</td>
<td>16.000</td>
</tr>
<tr>
<td>6</td>
<td>16.250</td>
</tr>
<tr>
<td>7</td>
<td>16.500</td>
</tr>
<tr>
<td>8</td>
<td>16.750</td>
</tr>
<tr>
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### TABLE 2.15.28 ROSKAM-FILLMAN METHOD

**CONFIGURATION J (31 PAX, 2/2)**

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### Table 2.15.3A Roskam-Fillman Method

**Configuration J (31 Pax, 2/2)**

**Sensitivity of Wetted Area to Tail Cone Length**

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## TABLE 2.15.33 ROSKAM-FILLMAN METHOD

**CONFIGURATION J (31 PAX, 2/72)**

**SENSITIVITY OF ZERO-LIFT DRAG TO TAIL CONE LENGTH**

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**ORIGINAL COO/HV** 0.00937
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This appendix documents the program FUSE and how to use it. Appendix C1 will describe the preparation of input data for both the simulation and design modes of the program. Default values for the design mode are also documented in this section. Appendix C2 will explain how the program was operated on the Honeywell 66/60 timesharing system and about the different operation options that were available. Appendix C3 provides a copy of the program listing.

C1 Preparation of Input Data

FUSE may be operated in either of two modes—the simulation mode or the design mode. In the simulation mode input data are read from a separate disc file set up like a card data deck (Logical unit no. 03). In the design mode data are input by means of an interactive question and answer sequence. Each of these methods will be dealt with in turn. To aid in understanding the input computer acronyms, Table C-1 has been prepared.
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Variable</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>H</td>
<td>Cabin height</td>
<td>ft</td>
</tr>
<tr>
<td>LBD</td>
<td>( \lambda_{B/D} )</td>
<td>Fuselage fineness ratio</td>
<td></td>
</tr>
<tr>
<td>LC</td>
<td>( \lambda_c )</td>
<td>Tail cone length</td>
<td>ft</td>
</tr>
<tr>
<td>LCD</td>
<td>( \lambda_c/D )</td>
<td>Tail cone fineness ratio</td>
<td></td>
</tr>
<tr>
<td>LLN</td>
<td>( L_{N1}/L_{N2} )</td>
<td>Ratio of nose cone lengths</td>
<td></td>
</tr>
<tr>
<td>LNI</td>
<td>( L_{N1} )</td>
<td>Cone N1 length</td>
<td>ft</td>
</tr>
<tr>
<td>LN2</td>
<td>( L_{N2} )</td>
<td>Cone N2 length</td>
<td>ft</td>
</tr>
<tr>
<td>LU</td>
<td>( L_u )</td>
<td>Cabin (utility) length</td>
<td>ft</td>
</tr>
<tr>
<td>NFORX</td>
<td>-</td>
<td>Array containing number of lengthwise divisions per fuselage section</td>
<td></td>
</tr>
<tr>
<td>NFORX(1)</td>
<td>-</td>
<td>Number of lengthwise divisions for the nose</td>
<td></td>
</tr>
<tr>
<td>NFORX(2)</td>
<td>-</td>
<td>Number of lengthwise divisions for the cabin</td>
<td></td>
</tr>
<tr>
<td>NFORX(3)</td>
<td>-</td>
<td>Number of lengthwise divisions for the tail cone</td>
<td></td>
</tr>
<tr>
<td>NFUS</td>
<td>-</td>
<td>Number of fuselage sections to be simulated; (&lt; 3)</td>
<td></td>
</tr>
<tr>
<td>NRADX</td>
<td>-</td>
<td>Number of radial divisions</td>
<td></td>
</tr>
<tr>
<td>PH11</td>
<td>( \phi_{11} )</td>
<td>Cone N1 taper shape parameter (Side view)</td>
<td></td>
</tr>
<tr>
<td>PH21</td>
<td>( \phi_{21} )</td>
<td>Cone N1 bluntness shape parameter (Side view)</td>
<td></td>
</tr>
<tr>
<td>Acronym</td>
<td>Variable</td>
<td>Description</td>
<td>Units</td>
</tr>
<tr>
<td>---------</td>
<td>----------</td>
<td>-------------</td>
<td>-------</td>
</tr>
<tr>
<td>PH12</td>
<td>$12</td>
<td>Cone N2 taper shape parameter (Side view)</td>
<td></td>
</tr>
<tr>
<td>PH22</td>
<td>$22</td>
<td>Cone N2 bluntness shape parameter (Side view)</td>
<td></td>
</tr>
<tr>
<td>PHY1</td>
<td>$y1</td>
<td>Cone N1 taper shape parameter (Top view)</td>
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</tr>
<tr>
<td>PHY2</td>
<td>$y2</td>
<td>Cone N1 bluntness shape parameter (Top view)</td>
<td></td>
</tr>
<tr>
<td>PHC1</td>
<td>$c1</td>
<td>Tail cone taper shape parameter</td>
<td></td>
</tr>
<tr>
<td>PHC2</td>
<td>$c2</td>
<td>Tail cone bluntness shape parameter</td>
<td></td>
</tr>
<tr>
<td>QC1</td>
<td>q_{C1}</td>
<td>Coefficient of ((x')) for the cone offset equation</td>
<td></td>
</tr>
<tr>
<td>QC2</td>
<td>q_{C2}</td>
<td>Coefficient of ((x')^2) for the tail cone offset equation</td>
<td></td>
</tr>
<tr>
<td>QN1</td>
<td>q_{N1}</td>
<td>Coefficient of (x) for the cone N1 offset equation</td>
<td></td>
</tr>
<tr>
<td>QN2</td>
<td>q_{N2}</td>
<td>Coefficient of (x^2) for the cone N1 offset equation</td>
<td></td>
</tr>
<tr>
<td>RBI</td>
<td>r_{bl1}</td>
<td>Cone N1 round-off radius, bottom</td>
<td></td>
</tr>
<tr>
<td>RB2</td>
<td>r_{bl2}</td>
<td>Cone N2 round-off radius, bottom</td>
<td></td>
</tr>
<tr>
<td>RBC</td>
<td>r_{bc}</td>
<td>Cabin round-off radius, bottom</td>
<td></td>
</tr>
<tr>
<td>RBT</td>
<td>r_{bt}</td>
<td>Tail round-off radius, bottom</td>
<td></td>
</tr>
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</table>
### Table C-1 FUSE Input Acronyms (Cont'd)

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Variable</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
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<td>RT1</td>
<td>$r_{t1}$</td>
<td>Cone N1 round-off radius, top</td>
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</tr>
<tr>
<td>RT2</td>
<td>$r_{t2}$</td>
<td>Cone N2 round-off radius, top</td>
<td></td>
</tr>
<tr>
<td>RTC</td>
<td>$r_{tc}$</td>
<td>Cabin round-off radius, top</td>
<td></td>
</tr>
<tr>
<td>RTT</td>
<td>$r_{tt}$</td>
<td>Tail round-off radius, top</td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>$w$</td>
<td>Cabin width</td>
<td>ft</td>
</tr>
<tr>
<td>YN1</td>
<td>$y_{N1}$</td>
<td>Half width of Cone N1 at $x = s_{N1}$</td>
<td></td>
</tr>
<tr>
<td>ZNO</td>
<td>$z_{NO}$</td>
<td>Vertical offset of Cone N1 at $x = 0$</td>
<td>ft</td>
</tr>
<tr>
<td>ZN1</td>
<td>$z_{N1}$</td>
<td>Half height of Cone N1 at $x = s_{N1}$</td>
<td>ft</td>
</tr>
<tr>
<td>ZZC</td>
<td>$\left(\frac{2z_{O}}{H}\right)^{\frac{1}{2}} - B$</td>
<td>Tail cone offset</td>
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<tr>
<td>ZZN</td>
<td>$\frac{z_{N1}}{H}$</td>
<td>Ratio of nose cone heights</td>
<td></td>
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</table>
1.1 Simulation Mode Input Data

As was stated, in the simulation mode data are read from a disc file set up like a data card deck. In other words, each line of the file represents a different data card. The file must be sequential. Also only one simulation data deck may be run at a time. Table C-2 provides a guide for the "card" formats.

Most of the input data required for FUSE are relatively simple to derive from a drawing of the fuselage desired. The nose, however, and the offset cones in general can sometimes present difficulties. In checking out FUSE several methods for determining the shape parameters for the nose were tried. The method that will be described in the following paragraphs consistently produced the best results.

Figures C-1 and C-2 provide the top, side, and front views for the nose of the Gates Learjet 35/36. These views will be used to determine the nose shape input parameters for FUSE.

The length of the nose, $l_{N1}$, is chosen to extend to the point where the fuselage cabin cross-section can best be said to become constant. Usually this will occur just aft of the crew compartment. The elliptical cones are modelled such that the planform curves are perpendicular to the cross-sectional plane at the base of nose section $(x = l_{N1})$. This should also be considered when the nose section length is chosen. The length of Cone N2, $l_{N2}$, is determined by fairing the windshield curve down to the fuselage centerline as shown in Figure C-1.
### Table C-2 Simulation Mode Input Data

#### Card Format

**INPUT CARD NO. 1 - (513)**

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<th>NFORX</th>
<th>NRADX</th>
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<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>7</td>
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**INPUT CARD NO. 2 - (18A4)**

**TITLE**

**INPUT CARD NO. 3 - (7F10.0)**

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<th>LN</th>
<th>LN2</th>
<th>LU</th>
<th>LC</th>
<th>W</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>21</td>
<td>31</td>
<td>41</td>
<td>51</td>
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</table>

**INPUT CARD NO. 4 - (7F10.0)**

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<th>PH1</th>
<th>PH2</th>
<th>PH1</th>
<th>PH2</th>
<th>PHC1</th>
<th>PHC2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>21</td>
<td>31</td>
<td>41</td>
<td>51</td>
</tr>
<tr>
<td>INPUT CARD NO. 5 - (7FI0.0)</td>
<td>PHY1</td>
<td>PHY2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>----------------------------</td>
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<tr>
<td></td>
<td>1</td>
<td>11</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>INPUT CARD NO. 6 - (7FI0/0)</th>
<th>YNI</th>
<th>ZN1</th>
<th>ZN0</th>
<th>QN1</th>
<th>QN2</th>
<th>QC1</th>
<th>QC2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>11</td>
<td>21</td>
<td>31</td>
<td>41</td>
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<table>
<thead>
<tr>
<th>INPUT CARD NO. 7 - (7FI0.0)</th>
<th>RTI</th>
<th>RB1</th>
<th>RT2</th>
<th>RB2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>11</td>
<td>21</td>
<td>31</td>
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</table>

<table>
<thead>
<tr>
<th>INPUT CARD NO. 8 - (7FI0.0)</th>
<th>RTC</th>
<th>RBC</th>
<th>RTT</th>
<th>RBT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>11</td>
<td>21</td>
<td>31</td>
</tr>
</tbody>
</table>
NOTE: SCALE: 1/40

NOSE SHAPE PARAMETERS (SIDE VIEW)

\[ \begin{align*}
\ell_{N1} &= 10.58 \text{ ft.} \\
\ell_{N2} &= 5.63 \text{ ft.} \\
H &= 5.48 \text{ ft.} \\
z_{N0} &= -1.83 \text{ ft.} \\
z_{N1} &= 1.90 \text{ ft.}
\end{align*} \]

\[ \begin{align*}
z_0 &= -1.83 + 0.195x - 0.00834x^2 \\
\phi_{11} &= 0.651 \\
\phi_{21} &= 0.825 \\
\phi_{12} &= 0.598 \\
\phi_{22} &= 0.749
\end{align*} \]
NOTE: SCALE: 1/40

NOSE SHAPE PARAMETERS
(TOP VIEW)

\[ l_{N_1} = 10.58 \text{ ft.} \]
\[ W = 5.48 \text{ ft.} \]
\[ y_{N_1} = 2.61 \text{ ft.} \]
\[ \phi_{y_1} = 0.644 \text{ ft.} \]
\[ \phi_{y_2} = 0.805 \text{ ft.} \]
The values for the Cone N2 shape parameters, $\phi_{12}$ and $\phi_{22}$, are easily calculated by constructing the box and diagonals of Figure A-4 around the windshield cone. This has been accomplished in Figure C-1. The values for these shape parameters are also presented in Figure C-1.

As Cone N1 is deformed and offset, the procedure becomes slightly more difficult. The first step is to fair the curve of the upper surface back to the base of the nose section. Again, in accomplishing this it should be remembered that the planform curves must be perpendicular to the cross-sectional plane at the base of the nose section. The centerline of the deformed cone is then constructed. By applying a parabolic curve fit routine the equation for $z_0$ is established. In this case a parabolic regression analysis was performed using a curve fit routine in the BASIC language. A listing of this program is provided in Appendix D. All offsets are referenced to the centerline of the fuselage.

The half-height of Cone N1, $z_{N1}$, measured as shown in Figure C-1. This will always be a positive value.

The shape parameters, $\phi_{11}$ and $\phi_{21}$, cannot be properly determined from the deformed cone. Instead the cone is projected onto a straightened centerline of length, $l_{N1}$, as shown. The shape parameters are then calculated by the rectangle and diagonals. The method for determining the geometry of a deformed elliptical cone may also be applied to the fuselage tail cone.
Figure C-2 pictures the top and front views of the nose section. The front view is used to determine what the maximum width of Cone N1 at the nose section base must be. To avoid discontinuities at the base of the nose section, \( y_{N1} \) should be no greater than the \( y \)-value of the cabin a distance \( z_{N1} \) above the bottom of the cabin. This has been demonstrated in Figure C-2. The shape parameters \( \phi_1 \) and \( \phi_2 \) are then calculated in the usual manner.

The cabin input parameters are relatively straightforward and should be easily determined. The length of the cabin is \( L_u \) - or that part of the fuselage which may be simulated by a cylinder. The width of the cabin is \( W \) and the height is \( H \).

The tail cone shape parameters should be computed in a manner similar to that of the nose cones. The only differences are that the taper shape parameter, \( \phi_{1C} \), is calculated as the average of the top and side view taper shape parameters, and that the bluntness shape parameter, \( \phi_{2C} \), is the average of the top and side view bluntness shape parameters.

Table C-3 below provides a listing of the input data file for the Gates-Learjet 35/36.

<table>
<thead>
<tr>
<th>Table C-3</th>
<th>Listing of the Data File for the Gates-Learjet 35/36</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 7 7 15 19</td>
<td>GATES-LEARJET 35/36 -- 530 PANELS</td>
</tr>
<tr>
<td>10.58</td>
<td>5.63</td>
</tr>
<tr>
<td>0.651</td>
<td>0.825</td>
</tr>
<tr>
<td>0.644</td>
<td>0.805</td>
</tr>
<tr>
<td>2.61</td>
<td>1.90</td>
</tr>
<tr>
<td>1.</td>
<td>1.</td>
</tr>
<tr>
<td>1.</td>
<td>1.</td>
</tr>
<tr>
<td>1.</td>
<td>1.</td>
</tr>
<tr>
<td>1.</td>
<td>1.</td>
</tr>
</tbody>
</table>
C1.2 Design Mode Input Data

Design Mode data are input by an interactive question and answer sequence. The most effective way to describe this procedure is to follow the procedure for an example design. Such an example will be provided here. In this example underlined statements are those typed by the operator. The symbol "+" will be used to indicate a carriage return. Note that all of the following questions and answers documented here occur after the program has been compiled and execution begun.

```
DESIGN OR SIMULATION MODE?
ENTER D OR $
=+$
PRINT DIMENSIONS? Y FOR YES, N FOR NO
=Y+
PRINT FUSELAGE COORDINATES? Y OR N
=Y+
PRINT TOTAL WETTED AREA? Y OR N
=Y+
PRINT PANEL AREAS AND RATIOS? Y OR N
=N+
PLOT FUSELAGE? Y OR N
=N+
BUSINESS JET OR PISTON COMMUTER?
ENTER J OR P
=P+
```

The questions about printing data and plotting the fuselage are asked for either the design or simulation mode. They are included here for the sake of continuity but will be discussed in detail in Appendix C2. The question as to whether a jet or piston aircraft is to be designed determines which default values are to be used when needed. These values will be discussed later.
If the question, "ELLIPTICAL OR CIRCULAR CROSS-SECTION?", had been answered with yes, FUSE would have assumed that all round-off radii were equal to 1.0.

STEP: PASSENGERS, SEATS : BREAST, PITCH
= 25, 3, 30
SEAT WIDTH : AISLE WIDTH
= 20.18
DESIRED INSIDE CABIN HEIGHT? (IN.)
= 70
FUSELAGE WIDTH = 6.92 FT
SHOULD H = W? Y OR N
= N
INPUT H? Y OR N
= N

FUSELAGE HEIGHT = 6.44 FT
INSIDE CABIN HEIGHT = 70.00 IN.

If the operator had decided that \( r \) should equal W, then the desired inside cabin height is over-ridden. In this case the inside
cabin height is computed according to the McDonnell Douglas method documented in Chapter 2, and is output. Due to a programming oversight, if \( H \) is chosen to be input, the desired inside cabin height is output although this may no longer be valid.

```
BAGGAGE COMPARTMENT? Y OR N
= Y
ML, L, Z, Z, Z
= N
PH11, PH21, PH12, PH22, PHY1, PHY2
= N
LED, LCD, ZZC
= N
PHC1, MUCF
= N
```

For this example a baggage compartment was chosen to be included. The baggage compartment is sized according to Section 2.4. The shape parameters were chosen to be default values in the example above. The use of commas alone implies values of zero for each parameter. A value of zero tells the program to select the appropriate default value. The parameters above are all defined in Table C-1.

With the data as input above the program will determine the aircraft size and compute the node coordinates.

The default values that have been mentioned are tabulated in Table C-4. These values have no statistical value. They were chosen during the programming stage rather arbitrarily. At that time it was felt that they did however generate designs which were representative of each of these two airplane types.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Jet</th>
<th>Piston</th>
</tr>
</thead>
<tbody>
<tr>
<td>LLN</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>ZZN</td>
<td>.75</td>
<td>.75</td>
</tr>
<tr>
<td>ZNφ</td>
<td>Zφ</td>
<td>_{x=\phi N1}</td>
</tr>
<tr>
<td>φ_H</td>
<td>.65</td>
<td>.65</td>
</tr>
<tr>
<td>φ_{21}</td>
<td>.825</td>
<td>.85</td>
</tr>
<tr>
<td>φ_{12}</td>
<td>.60</td>
<td>.60</td>
</tr>
<tr>
<td>φ_{22}</td>
<td>.75</td>
<td>.725</td>
</tr>
<tr>
<td>φ_{y1}</td>
<td>.64</td>
<td>.65</td>
</tr>
<tr>
<td>φ_{y2}</td>
<td>.825</td>
<td>.85</td>
</tr>
<tr>
<td>LED</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>LCD</td>
<td>4.0</td>
<td>3.5</td>
</tr>
<tr>
<td>ZZC</td>
<td>.75</td>
<td>.75</td>
</tr>
<tr>
<td>φ_{1c}</td>
<td>.60</td>
<td>.60</td>
</tr>
<tr>
<td>φ_{2c}</td>
<td>.775</td>
<td>.80</td>
</tr>
</tbody>
</table>
C3  Program Operation

This program was written for the Honeywell 66/60 timesharing system. Consequently, many of the commands that will be described here will not be the same or perhaps even applicable on other systems. An attempt will be made to explain the reasons for each so that it will be possible for the reader to evaluate his own application.

C3.1 Program Initialization

As FUSE is written to be used with the Tektronix PLOT 10 graphics software package, and because it is sometimes necessary to read from, or write to, other disc files, it is necessary to link the program file with several others before compiling. This is accomplished as described in the following paragraphs.

Three files were required to operate the PLOT 10 package. The names for these on the University of Kansas system were ADBOUT, ADEIN, and OBJECT. To be linked with FUSE these files had to be placed on the Available File Table (AFT) for the KU-FRL project computer account. Each project account is identified by what is referred to as a Project Identifier (PI). To place a file in the AFT three things must be given: the PI under which the file is stored; the catalog name (if any) under which the file is stored; and the filename. Then the command is:

GET PI/CATALOG/FILENAME +

If a logical unit number (L) is to be assigned to the file
when it is stored in the AFT, then the command becomes:

GET PI/CATALOG/FIILENAME"L" +

For the case of FUSE this might be accomplished as:

SYSTEM? GET 7684WALLACE/PL0T10/ADEOUT +
SYSTEM? GET 7684WALLACE/PL0T10/ADEIN +
SYSTEM? GET 7684WALLACE/PL0T10/OBJECT +
SYSTEM? GET 7102DESIGN/LEARJET"03" +
SYSTEM? GET 7102DESIGN/LEARCOORD"07" +

This would gather the PLOT10 files, and LEARJET and LEARCOORD
onto the AFT. LEARJET would be assigned the logical unit number "03"
(to be read from) and LEARCOORD, the logical unit number "07" (to be
written to).

To load FUSE onto the AFT for use as a FORTRAN program the
command was:

SYSTEM? FORTRAN +

OLD FILE OR NEW - OLD FUSE +

And to compile and execute:

* RUNH * ADEOUT; ADEIN; OBJECT +

FUSE, in this case, is referred to as the star-level file;
hence the * after the command RUNH. LEARJET and LEARCOORD are input/
output files to be referred to by the program and therefore are not
needed in the run command. Having completed these commands, the
program is compiled and executed.
C2.2 Output Options

There are six output options available for both the design and simulation modes:

1) Print Dimensions
2) Print Coordinates
3) Print Total Wetted Area
4) Print Panel Areas and Ratios
5) Plot Fuselage
6) File Data

If dimensions are output, the result will appear either as in Table C-5a or as in Table C-5b, depending on whether the design or simulation mode is selected. Note that at the end of each printout, the operator is asked whether the data were satisfactory. If not, he is given the choice of resubmitting his input or terminating execution. When the dimensions are satisfactory, he may choose to file data.

If coordinates are output, the result will appear as in Table C-6. The I and J value locate the node longitudinally and radially, respectively; and the X, Y, and Z values provide the coordinates in feet.

Total wetted area of the fuselage appears as shown below:

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
TOTAL WETTED AREA = 769.52
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
Panel areas and ratios are output as shown in Table C-7. In this case, the I and J values locate the panels longitudinally and radially. The area of the panel is in ft². RATIO J is the ratio of the area of that panel to the (I,J-1) panel, and RATIO I is the ratio of the area of that panel to the (I-1,J) panel.

If a plot is requested, the fuselage is plotted on the graphics terminal similarly to the plots presented in Figures 2.43 and 2.44. The major difference is that the actual aircraft fuselage lines are not superimposed.

If it is requested that data be filed, the fuselage coordinates are filed in a manner compatible with the input data formats of the NCSU BODY program of Reference 20.
Table C-5a  Dimension Printout for Design Mode

CONFIGURATION -- S: VAPOR POINT-CFF

FUSELAGE MODE -- D

DIVISIONS

<table>
<thead>
<tr>
<th>DIVISION</th>
<th>10</th>
<th>7</th>
<th>12</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>RADIAL (HALF FUSELAGE)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LENGTHWISE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOSE</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>CABIN</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TAIL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CABIN CONFIGURATION

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<tr>
<th>ITEM</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NO. OF PASSENGERS</td>
<td>25</td>
</tr>
<tr>
<td>SEATS PER ROW</td>
<td>3</td>
</tr>
<tr>
<td>NO. OF ROWS</td>
<td>9</td>
</tr>
</tbody>
</table>

FUSELAGE GEOMETRY

<table>
<thead>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NOSE CONE N1</td>
<td>10.96</td>
<td>2.42</td>
<td>3.35</td>
<td></td>
</tr>
<tr>
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<td>0.650</td>
<td>2.356</td>
<td>0.659</td>
<td>0.359</td>
</tr>
<tr>
<td>PH11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PH21</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHY1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHY2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DIVISION</th>
<th>LENGTH</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NOSE CONE N2</td>
<td>6.26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHAPE PARAMETERS</td>
<td>9.686</td>
<td>9.725</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PH12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PH22</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DIVISION</th>
<th>LENGTH</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CABIN</td>
<td>29.17</td>
<td>6.44</td>
<td>6.82</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DIVISION</th>
<th>LENGTH</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>TAIL CONE</td>
<td>23.33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHAPE PARAMETERS</td>
<td>2.488</td>
<td>2.329</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHC1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHC2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DATA SATISFACTORY? Y OR N

FILE FUSELAGE DATA? Y OR N

=N

C.20
Table C-5b Dimension Printout for Simulation Mode

**GATEs-LEAPJET 35/36 -- F30 PANELS**

**FUSE PROGRAM NOTE -- 5**

**DIVISIONS**

- **Fuselage (half fuselage)**
  - **Length**
  - **Nose**
  - **Cabin**
  - **Tail**

**Fuselage Geometry**

<table>
<thead>
<tr>
<th>Component</th>
<th>Length</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nose Cone N1</td>
<td>10.58</td>
<td>1.96</td>
</tr>
<tr>
<td>Nose Cone N2</td>
<td>5.63</td>
<td></td>
</tr>
<tr>
<td>Cabin</td>
<td>10.34</td>
<td>5.48</td>
</tr>
<tr>
<td>Tail Cone</td>
<td>25.33</td>
<td></td>
</tr>
</tbody>
</table>

**Shape Parameters**

<table>
<thead>
<tr>
<th>Component</th>
<th>PF11</th>
<th>PHC1</th>
<th>PHY1</th>
<th>PHY2</th>
</tr>
</thead>
<tbody>
<tr>
<td>PF11</td>
<td>0.651</td>
<td>0.825</td>
<td>0.644</td>
<td>0.895</td>
</tr>
<tr>
<td>PHC1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHY1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHY2</td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

**DATA SATISFACTORY? Y OR N**

**FILE FUSELAGE DATA? Y OR N**

**Y**

C.21
### Table C-6 Example Coordinate Printout

<table>
<thead>
<tr>
<th>I</th>
<th>J</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0.</td>
<td>0.</td>
<td>-0.964</td>
</tr>
<tr>
<td>1</td>
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<td>-0.964</td>
</tr>
<tr>
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<td>-0.964</td>
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<tr>
<td>1</td>
<td>4</td>
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<td>-0.964</td>
</tr>
<tr>
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<td>5</td>
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<td>-0.964</td>
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<td>-0.964</td>
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<tr>
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<td>7</td>
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<td>-0.964</td>
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<tr>
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<td>-0.964</td>
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<tr>
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<td>9</td>
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<td>-0.964</td>
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<tr>
<td>1</td>
<td>10</td>
<td>0.</td>
<td>0.</td>
<td>-0.964</td>
</tr>
<tr>
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<tr>
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<td>0.</td>
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</tr>
<tr>
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<td>1.812</td>
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<td>1.812</td>
<td>1.320</td>
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<tr>
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<td>5</td>
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<td>-1.326</td>
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<td>6</td>
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<td>1.662</td>
<td>-0.803</td>
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<tr>
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<td>7</td>
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<td>1.460</td>
<td>-0.329</td>
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<td>6</td>
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</tr>
<tr>
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<td>7</td>
<td>3.625</td>
<td>2.009</td>
<td>0.010</td>
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<tr>
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<td>8</td>
<td>3.625</td>
<td>1.508</td>
<td>0.453</td>
</tr>
<tr>
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<td>9</td>
<td>3.625</td>
<td>0.981</td>
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<td>0.834</td>
</tr>
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<td>11</td>
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<td>5.437</td>
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<td>-2.778</td>
</tr>
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<td>5.437</td>
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C3 FUSE Listing

This section provides a complete listing of the fuselage shape simulation program, FUSE.
APPENDIX D  PARABOLIC LEAST-SQUARES
CURVE-FIT ROUTINE

This appendix presents a listing for a time-sharing program in BASIC to compute the coefficients for a least-squares parabolic curve-fit of the general form:

\[ Y = a_0 + a_1 x + a_2 x^2. \]
0010 DIM D(10, 2), A(3, 3), B(3), C(3)
0020 PRINT "NUMBER OF DATA POINTS?"
0030 INPUT N
0040 PRINT "INPUT DATA; X, Y"
0050 FOR I = 1 TO N
0060 INPUT D(I, 1), D(I, 2)
0070 NEXT I
0080 FOR I = 1 TO N
0090 PRINT D(I, 1), D(I, 2)
0100 NEXT I
0110 X1 = 0.
0120 X2 = 0.
0130 X3 = 0.
0140 X4 = 0.
0150 Y1 = 0.
0160 Y2 = 0.
0170 Y3 = 0.
0180 Y4 = 0.
0190 Y5 = 0.
0200 S1 = 0.
0210 S2 = 0.
0220 FOR I = 1 TO N
0230 X1 = X1 + D(I, 1)
0240 X2 = X2 + D(I, 1) + D(I, 1)
0250 X3 = X3 + D(I, 1) + D(I, 1) + D(I, 1)
0260 X4 = X4 + D(I, 1) + D(I, 1)
0270 Y1 = Y1 + D(I, 2)
0280 Y2 = Y2 + D(I, 1) + D(I, 2)
0290 Y3 = Y3 + D(I, 1) + D(I, 1) + D(I, 2)
0300 Y5 = Y5 + D(I, 2) + D(I, 2)
0310 NEXT I
0320 Y4 = Y1 / N
0330 B(1) = Y1
0340 B(2) = Y2
0350 B(3) = Y3
0360 A(1, 1) = N
0370 A(2, 1) = X1
0380 A(1, 2) = X1
0390 A(2, 2) = X2
0400 A(1, 3) = X2
0410 A(3, 1) = X2
0420 A(2, 3) = X3
0430 A(3, 2) = X3
0440 A(3, 3) = X4
0450 MAT A = INV(A)
0460 MAT C = A * B
0470 S2=(Y5-C(1))\*Y1-C(2))\*Y2-C(3))\*Y3)/N
0480 S2=S2+S2
0490 FOR I=1 TO N
0500 Y=Y+(D(I,2, -Y4)+2
0510 NEXT I
0520 S1=Y/N
0530 R2=1.-S2/S1
0540 PRINT "A0 ="; C(1)
0550 PRINT "A1 ="; C(2)
0560 PRINT "A2 ="; C(3)
0570 PRINT "COEFF. OF DET.,R2 ="; R2
0580 STOP
0590 END