SKETCH: A COMPUTER PROGRAM FOR PLOTTING A TRANSPORT AIRPLANE CONFIGURATION IN CONCEPTUAL DESIGN

C. Bil

Delft - The Netherlands  Juni 1983
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Summary.

This report describes a computer program, called SKETCH, for 'automatically' plotting an elementary airplane configuration drawing (wing + fuselage + tailplanes + nacelles).

SKETCH was developed intentionally for application in conceptual design studies of transport airplanes. The wing and tailplanes geometries are derived from the major design parameters, e.g. wing area, aspect ratio, sweep angle, tail volume coefficients, etc. Non-dimensional parameters are used to define the location of the components and to allow rapid reorientation without losing the coherency of the configuration.

Results of SKETCH applied to some existing airplanes are presented. Appendix C includes directions for use of the program.

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LIST OF SYMBOLS

A - aspect ratio (no index: wing)
b - span (no index: wing)
$C_1, C_2, C_3$ - coefficients in F-function
c - chord
c - mean aerodynamic chord (no index: wing)
D - diameter
d - distance
e - exponent
F - tailplane function
H - height
i - wing/fuselage incidence
k - non-dimensional input parameter
L - length
S - area (no index: wing)
t - thickness
VOL - tail volume coefficient
W - width
X - coordinate longitudinal axis
Y - coordinate spanwise axis
Z - coordinate top axis
$\Gamma$ - dihedral (no index: wing)
$\varepsilon$ - wing geometric twist, tilt angle of engine nacelle
$\theta$ - positional parameter for fuselage-mounted engines
$\Lambda$ - sweep angle (no index: wing)
$\lambda$ - taper ratio (no index: wing)
$\phi$ - toe angle of engine nacelle
Subscripts

e - engine, exhaust
f - fuselage, fan
g - gasgenerator
h - horizontal tailplane
i - intake highlight
k - iteration step counter
l - lower
MW - maximum width
max - maximum
n - nacelle
r - root
ref - reference
s - scaled
t - tip
u - upper
TE - trailing edge
v - vertical tailplane
w - wing
1. Introduction.

Configuration drawings play a major role in airplane design:

- They are a communication interface between design groups, production and manufacturing department, management, customers, etc.
- They are used as an aid for the positioning and arrangement of internal and external components, such as systems, avionics, cabin and flight deck layout, wing, engines, tail surfaces, undercarriage, etc., and provide information regarding clearances, structural integration and interference between components.
- Dimensions, angles, areas and other geometric properties can be derived from the drawing.

As computer-aided design (CAD) becomes usual practice in airplane design, drawing-boards are replaced by graphics displays. Computer software, e.g. CADAM, CATIA, MEDUSA, McAuto, etc., is being developed and marketed to support these activities. These, often general, graphics systems are intended for producing detailed drawings of objects constructed interactively in a line after line fashion. Hence, these systems can only be used efficiently when the airplane configuration is fixed or only a few minor changes may be expected. In the conceptual and preliminary design phase however, design parameters such as wing area, aspect ratio, sweep angle, etc., effecting the airplane geometry, are frequently changed.

In the early stages of the design, a computer program is desired that 'automatically' draws an airplane configuration with the dimensions derived from the major design parameters and the location of the components, i.e. wing, engines and tailplanes, defined in a non-dimensional form to allow rapid reorientation without losing coherency. The program alone can not be used to design an airplane, but its main purpose is to visualize an airplane configuration of which the design parameters are already available and to present the designer with information in order to assess the general appearance of the design. As such, the program may be a useful tool in an airplane design process.

This report presents an example of this type of program (SKETCH) (Lit. 1), developed on the central graphics system (PDP 11/45 with a Tektronix 4014 display) at the Computing Center, Delft University of Technology. Considering the limited amount of data available in the conceptual design phase, some simplifications were necessary, but they are acceptable in view of the purpose of the program.
2. **Program structure.**

The program is coded in FORTRAN IV and uses GPGS 3D-plot routines (Lit. 2 and 3).

The modular structure facilitates future modifications to the program. The main program consists of four modules (Figure 1):

- Read input data from a file.
- Compute all derivative dimensions and angles from the input design parameters.
- Plot a 3-view configuration drawing.
- Plot a 3D wire frame model at a user specified orientation.

These modules are subdivided into subroutines which perform computations or plotting for each component separately. The size of the program (100k bytes) necessitates the use of overlays (Figure 1).

3. **Required input data.**

In the following sections, the primary input parameters to SKETCH will be reviewed.

3.1. **Fuselage geometry.**

The fuselage geometry is derived from the projections of the contour lines in side and plan view. The contour lines are subdivided into straight and curved line segments. The curved lines are splines of the mathematical form:

\[ y_s = (1 - x_s^{e_x})^{e_y} y, \tag{3-1} \]

where the exponents \( e_x \) and \( e_y \) are independent variables. This type of spline is in fact an extension to, so called, generalized ellipses or superellipses (Lit. 4), for which \( e_x = e_y \). Some mathematical properties of the spline are analyzed in more detail in appendix A.

Each line segment is bounded by 2 endpoints, the coordinates of which, relative to a fixed axes-system, are to be specified by the user (Figure 2). In addition, the shape of each spline can be controlled by specifying the exponents \( e_x \) and \( e_y \) directly or by imposing a mathematical constraint from which they can be derived.

Figure C2 gives a summary of the available options to control the shape of each spline.
The projection of the plan view contour line (maximum width line) on the xz-plane (side view) is determined by 2 control points \( P_{23} \) and \( P_{24} \). Between these 2 points, the maximum width line is parallel to the x-axis (fuselage datum line). From \( P_{23} \) to the fuselage nose and from \( P_{24} \) to the fuselage endpoint, the maximum width line lies at a constant fraction of the local fuselage height.

The shape of each cross-section is constructed from 2 common ellipses, \( e_x = 2 \) and \( e_y = 2 \) (Figure 2). Future modifications to SKETCH may include an option to vary \( e_x \) and \( e_y \) for the cross-sectional shape.

Obviously, increasing the number of line segments will result in a more flexible fuselage geometry routine, however, the required input data is proportional. For SKETCH, the number of line segments was selected such that the fuselage nose section of a B747 and the tail section of freighter type airplanes could be modelled.

Figure 3 presents some examples of fuselage shapes produced with the fuselage geometry routine.

3.2. Wing geometry and location.

The wing planform is restricted to a trapezoid, with or without a partly non-swept trailing edge. The following design parameters are required to define the wing geometry (Figure 4):

- Reference area \( S_{\text{ref}} \)
- Aspect ratio \( \lambda_{\text{w}} \)
- Quater-chord sweep angle \( \lambda_{w,\text{QC}} \)
- Taper ratio \( \lambda_{w,\text{T}} \)
- Thickness/chord ratio at the root \( \frac{t}{c_{\text{w},\text{R}}} \)
- Non-swept trailing edge length/semi-span \( k_{\text{w},\text{FTE}} \)
- Geometric twist \( \varepsilon_{\text{w}} \)
- Thickness/chord tip/root ratio \( \frac{t}{c_{\text{w},\text{T}}} \)
- Airfoil crest location/chord ratio \( \frac{k_{\text{cr},\text{R}}}{c_{\text{w},\text{R}}} \)
- Airfoil crest location/chord ratio \( \frac{k_{\text{cr},\text{T}}}{c_{\text{w},\text{T}}} \)

Where applicable, the parameters, e.g. aspect ratio, taper ratio, etc., refer to the reference area.

The airfoil shape applied in SKETCH for the wing and the tailplanes, is symmetrical, with an elliptical nose section and a straight rear section. The crest location relative to the chord at the root and the tip can be set
by the parameters $k_{cr_h}$ and $k_{cr_v}$ respectively. For the tailplanes these parameters are fixed at 25%.

The wing location and orientation is determined by the following parameters (Figure 4):

- Wing/fuselage incidence ($i_w$)
- Dihedral ($\Gamma_w$)
- Distance between wing root chord and fuselage bottom line/fuselage height ($k_{z_w}$)
- Distance between wing apex and fuselage nose/fuselage length ($k_{x_w}$)

By varying ZWING, a high-wing as well as a low-wing configuration can be drawn.

3.3. Horizontal and vertical tailplane geometry and location.

The parameters defining the horizontal and vertical tailplane geometry are (Figure 4):

- Horizontal tailplane volume coefficient $\left(\frac{s_h l_h}{s c}\right)$
- Vertical tailplane geometry coefficient $\left(\frac{s v l_v}{s d}\right)$
- Aspect ratio ($A_h$ and $A_v$)
- Taper ratio ($l_h$ and $l_v$)
- Thickness/chord ratio at the root ($t/c_{r_h}$ and $t/c_{r_v}$)
- Thickness/chord tip/root ratio ($k_{tr_h}$ and $k_{tr_v}$)

The tailplane areas are derived from the tail volume coefficients. This requires an iterative method, as the momentarms $l_h$ and $l_v$, i.e. the distance between the quarter-chord points of the wing and the tailplane, are a function of the respective tailplane areas. Appendix B gives a derivation of the equations involved and the application of the Newton-Raphson procedure for solving them.

The vertical tailplane is positioned with the root chord trailing edge coinciding with the fuselage endpoint. The horizontal tailplane root chord trailing edge coincides with the trailing edge of the local vertical tailplane chord. Since the horizontal tailplane momentarm depends on the vertical tailplane geometry, the vertical tailplane area is computed first.
The vertical position and the dihedral of the horizontal tailplane are defined by the following parameters (Figure 4):

- Distance between horizontal tailplane root chord and vertical tailplane root chord/vertical tailplane height \( \frac{k}{z_h} \)  
- Dihedral \( \Gamma_h \)

The parameter ZHTAIL can be used to select a T-tail or conventional tail.

3.4. Engine nacelles geometry.

The nacelle dimensions are, directly or indirectly, related to the overall length and diameter of the nacelle (Figure 5):

- Nacelle diameter \( D_n \)
- Intake highlight diameter/nacelle diameter \( k_{d_1} \)
- Fan exhaust diameter/nacelle diameter \( k_{d_{fe}} \)
- Gas generator exhaust diameter/gas generator diameter \( k_{d_{ge}} \)
- Gas generator diameter/fan exhaust diameter \( k_{d_g} \)
- Nacelle length \( L_n \)
- Fan cowling length/nacelle length \( k_{l_f} \)
- Fan forebody length/fan cowling length \( k_{l_1} \)

Upto four different nacelle geometries can be specified. The program automatically mirrors the nacelles with respect to the plane of symmetry, so upto eight engines can be drawn per airplane.

A nacelle is assumed to be a rotational symmetric body. The fan cowling contour lines are ellipsoids, while the gas generator contour lines are linear.

Although the described nacelle geometry is schematic, it proved sufficiently flexible to simulate a turboprop engine nacelle and an external fuel tank.

With respect to the location of the engines, a distinction is made between wing-mounted and fuselage-mounted engines. The following positional parameters are required for fuselage-mounted engines (Figure 6):

- Distance between highlight frontface and fuselage nose/fuselage length \( k_{x_e} \)
- Angle of the line through the centers of the fuselage and nacelle with the horizontal \( \Theta_e \)

If \( \Theta_e = 90^\circ \), no mirroring is performed and a center engine is drawn.
Stand-off distance/nacelle diameter \( \frac{k_d}{e} \)

For wing-mounted engines, the positional parameters are (Figure 6):  

- Distance between fuselage and nacelle centerline/semi-span \( \frac{k_y}{e} \)
- Distance between highlight frontface and local leading edge/ nacelle length \( \frac{k_x}{e} \)
- Distance between local chord and nacelle centerline/nacelle diameter \( \frac{k_z}{e} \)

In both cases, the engine nacelles can be rotated to off-set the thrust vector (Figure 6):

- Tilt angle \( \alpha \)
- Toe angle \( \phi \)

Pylons will not (yet) be drawn by SKETCH.

4. Results and conclusions.

A computer program has been developed to 'automatically' plot an elementary drawing of transport type airplanes.

Figure 7 gives examples of 3-view configuration drawings produced with SKETCH, while figure 8 presents some 3D wire frame models.

It can be concluded that SKETCH may be a useful tool in a computer-aided airplane design environment. It can, for instance, be linked to a sizing program to visualize the appearance of the sized airplane (Figure 9).

Future interfacing with a higher level graphics system may be considered to include hidden-line removal and the capability to use a drawing editor in order to add detail and refinement once the configuration is frozen.
5. Literature.


Figure 1: SKETCH program structure and overlays.
Figure 2: Control points to shape the fuselage contour lines.
Figure 3: Some examples of (half) fuselage models produced with fuselage geometry routine.
Figure 4: Wing and tailplanes geometry and location.
Figure 5: Engine nacelle geometry
Figure 6: Location of wing-mounted and fuselage-mounted engines.
Figure 7: Examples of 3-view configuration drawings produced with SKETCH.
Figure 8: Examples of 3D wire frame models produced with Sketch.
Figure 9: Sketch in a computer-aided airplane design environment.
Appendix A: Some mathematical properties of superellipses with unequal exponents.

The mathematical representation of superellipses with unequal exponents, as employed here, is:

$$y_s = (1 - x_s^e)^{e_y},$$  \hspace{1cm} (A-1)

where \(e_x\) and \(e_y\) may be varied independently.

The coordinates \((x_s', y_s')\) are scaled (normalized) to vary between 0 and 1 (Figure A1):

$$x_s = \frac{x - x_0}{x_1 - x_0} \quad (x_0 \leq x \leq x_1),$$  \hspace{1cm} (A-2)

and

$$y_s = \frac{y_1 - y}{y_1 - y_0} \quad (y_0 \leq y \leq y_1),$$  \hspace{1cm} (A-3)

where \((x_0, y_0)\) and \((x_1, y_1)\) are the endpoint coordinates of the spline (Figure A1).

Since \(x_s = 0\) for \(x = x_0\) and \(1 - x_s^e = 0\) for \(x = x_1\), \(e_x\) and \(e_y\) are constrained to:

$$e_x > 0$$  \hspace{1cm} (A-4)

and

$$e_y > 0$$  \hspace{1cm} (A-5)

The slope at the endpoints can be analyzed by differentiating (A-1) with respect to \(x_s^e\):

$$\frac{dy_s}{dx_s} = -e_x e_y (1 - x_s^e)^{e_y - 1} x_s^e.$$  \hspace{1cm} (A-6)
hence:

\[ \frac{dy_s}{dx_s} \leq 0 \quad \text{(no inflections)} \quad (A-7) \]

for \( 0 \leq x_s \leq 1 \).

So, for the endpoints the slopes are:

\[ x_s = 0 \]

\[ e_x = 1 \quad \Rightarrow \quad \frac{dy_s}{dx_s} = -e_y \quad (A-8) \]

\[ e_x > 1 \quad \Rightarrow \quad \frac{dy_s}{dx_s} = 0 \quad (A-9) \]

\[ 0 < e_x < 1 \quad \Rightarrow \quad \frac{dy_s}{dx_s} = -\infty \quad (A-10) \]

\[ x_s = 1 \]

\[ e_y = 1 \quad \Rightarrow \quad \frac{dy_s}{dx_s} = -e_x \quad (A-11) \]

\[ e_y > 1 \quad \Rightarrow \quad \frac{dy_s}{dx_s} = 0 \quad (A-12) \]

\[ 0 < e_y < 1 \quad \Rightarrow \quad \frac{dy_s}{dx_s} = -\infty \quad (A-13) \]

This illustrates a favourable property of this type of spline: for zero or infinite slope conditions at the endpoints, e.g. at the nose or at the tail section of the fuselage, only inequality constraints are imposed upon \( e_x \) and \( e_y \), and there is still some degree of freedom to control the shape of the spline.

Figure A2 shows the type of curves which can be obtained by varying \( e_x \) and \( e_y \).
In order to control the shape of the spline, the exponents \( e_x \) and/or \( e_y \) may be specified directly or may be derived from mathematical conditions, e.g. specified slopes at the endpoints, intermediate points through which the spline has to interpolate or a combination.

Two interpolation points requires the solution of a system of 2 non-linear equations, while there is no guarantee that (A-4) and (A-5) will be satisfied and is therefore not practical.

If one interpolation point \((x_{s1}, y_{s1})\) and one exponent, e.g. \(e_y\), is specified, the unknown exponent follows from (A-1):

\[
\frac{1}{e_x} \log(1 - \frac{y_{s1}}{y}) = \frac{\log(x_{s1})}{e_y}
\]

(A-14)

As shown in figure A3, the slope at \(x = 0\) depends on the location of \((x_{s1}, y_{s1})\) relative to the curve for which \(e_x = 1\). Figure A4 illustrates the type of curves obtained by varying \(e_y\) and deriving \(e_x\) from a given interpolation point condition.

Arbitrary slope conditions at both endpoints is mathematically not possible. An arbitrary slope condition at one endpoint determines both \(e_x\) and \(e_y\).

If, for example, the slope at \(x_s = 0\) is specified, the scaled gradient is:

\[
\frac{dy_s}{dx_s} \bigg|_{x_s = 0} = \frac{dy}{dx} \frac{dx}{dy} = -\frac{dy}{dx} \bigg|_{x = x_0} \frac{x_1 - x_0}{y_1 - y_0}
\]

(A-15)

From (A-8) it follows that:

\[
e_x = 1
\]

(A-16)

and from (A-8) and (A-15):

\[
e_y = \frac{dy}{dx} \bigg|_{x = x_0} \frac{x_1 - x_0}{y_1 - y_0}
\]

(A-17)

where \(\frac{dy}{dx} \bigg|_{x = x_0}\) is the given slope in absolute dimensions.
Note that the slope at \( x_s = 1 \) depends on the value of \( e_y \) and thus depends on the slope at \( x_s = 0 \) (Figure A5):

\[
-1 \leq \frac{\frac{dy_s}{dx_s}}{x_s = 0} \leq 0 \quad \Rightarrow \quad \frac{dy_s}{dx_s} = -\infty \quad (A-18)
\]

\[
\frac{dy_s}{dx_s} < -1 \quad \Rightarrow \quad \frac{dy_s}{dx_s} = 0 \quad (A-19)
\]

\[
\frac{dy_s}{dx_s} = -1 \quad \Rightarrow \quad \frac{dy_s}{dx_s} = -1 \text{ (straight line)} \quad (A-20)
\]

If the specified slope is 0 or \(-\infty\), eqs. (A-9) and (A-10) are in effect, so \( e_x \) and \( e_y \) remain undetermined.

The capability of specifying an arbitrary slope at one endpoint can also be used to blend (no discontinuity in the first derivative) two splines together. For a given spline, the scaled slope at an endpoint can be computed from (A-6) and from (A-8) or (A-11) follows the exponents of the neighboring spline.
Figure A1: Definition of normalized coordinates.

\[(X, Y) = (X_1, Y_1)\]
\[(X_S, Y_S) = (1, 0)\]

\[x_S = \frac{x - x_0}{x_1 - x_0}\]
\[y_S = \frac{y_1 - y}{y_1 - y_0}\]

\[y_S = (1 - x_S e_x)^{e_y}\]
Figure A2: Curves obtained by varying $e_x$ and $e_y$.

$$Y_s = (1 - X_s)$$
Figure A3: Effect of interpolation point condition on spline shape.

Figure A4: Curves obtained by varying $e_y$ and $e_x$ derived from an interpolation point condition.
\[
\alpha_{s} = \left( \frac{dY_s}{dX_s} \right)_{X_s=0} \\
\alpha_{1} = \left( \frac{dY_s}{dX_s} \right)_{X_s=1}
\]

Figure A5: Effect of slope condition on spline shape.
Appendix B: Determination of tailplane area from the tail volume coefficient and for a given wing location.

In the derivation, the following parameters are assumed to be known for the horizontal and vertical tailplane:

- aspect ratio
- taper ratio
- quarter-chord sweep angle
- tail volume coefficient

In addition, the wing and tailplanes are straight-tapered.

B.1. Distance of the wing MAC quarter-chord point from the fuselage nose.

The following equations are in effect:

\[ b = \sqrt{A \cdot S} \]  \hspace{1cm} (B-1)

and

\[ c_r = \frac{2}{1 + \lambda} \sqrt{\frac{S}{A}} \]  \hspace{1cm} (B-2)

The spanwise location of the mean aerodynamic chord (MAC) is:

\[ y_c = \frac{b}{2} \frac{1 + \frac{2\lambda}{3(1 + \lambda)}}{2} \]  \hspace{1cm} (B-3)

Hence, the distance of the MAC quarter-chord point from the fuselage nose is:

\[ l_c = x_{\text{apex}} + l_c r + y_c \tan \Lambda_{xc} = x_{\text{apex}} + \frac{1}{2(1 + \lambda)} \sqrt{\frac{S}{A}} \left\{ 1 + \frac{A}{3(1 + 2\lambda)\tan \Lambda_{xc}} \right\} \]  \hspace{1cm} (B-4)

where \( x_{\text{apex}} \) is the distance of the wing apex from the fuselage nose (cf. 3.2.).
B.2. Vertical tailplane area.

Similar to the wing, the distance of the MAC quarter-chord point from the fuselage nose is:

\[
\frac{1}{h_c} = X_{\text{apex}} + \frac{1}{2(1 + \lambda_v)} \sqrt{\frac{S_v}{A_v}} \left\{ 1 + \frac{A_v}{3(1 + 2\lambda_v) \tan \lambda_{1c_v}} \right\}
\]  

(B-5)

However, as the trailing edge of the vertical tailplane root chord is fixed at the fuselage endpoint (cf. 3.3.), the distance of the apex from the fuselage nose is:

\[
X_{\text{apex}} = l_f - c_r = l_f - \frac{2}{1 + \lambda_v} \sqrt{\frac{S_v}{A_v}}
\]  

(B-6)

where \( l_f \) is the fuselage length.

Substitution of (B-6) in (B-5) gives:

\[
\frac{1}{h_c} = l_f + \frac{1}{2(1 + \lambda_v)} \sqrt{\frac{S_v}{A_v}} \left\{ \frac{A_v}{3(1 + 2\lambda_v) \tan \lambda_{1c_v}} - 3 \right\}
\]  

(B-7)

The vertical tailplane area can now be calculated for a given tail volume coefficient:

\[
V_{\text{vol}} = \frac{S_v l_v}{S b}
\]  

(B-8)

where the moment arm is:

\[
l_v = l_f - l_{c_v} - h_c
\]  

(B-9)

Substitution of (B-7) and (B-9) in (B-8) and rearranging the equation gives:

\[
F(S_v) = S_v \left\{ \frac{\frac{S_v}{2} \left[ \frac{1}{3} \frac{\rho_v (1 + 2\lambda_v) \tan \lambda_{1c_v}}{3} - 3 \right]}{2(1 + \lambda_v) \sqrt{A_v}} \right\} + S_v \left( l_f - \frac{1}{h_c} \right)
\]  

\[
- SBV_{\text{vol}} = 0
\]  

(B-10)
Solving $S_v$ from (B-10) requires an iterative procedure (cf. B.4.).

B.3. Horizontal tailplane area.

A similar expression can be derived for the horizontal tailplane area. The distance of the MAC quarter-chord point from the fuselage nose is:

$$
\frac{1}{h_{ch}} = \frac{x_{apeh} - 1}{2(1 + \lambda_h)} \left[ 1 + \frac{\sqrt{\frac{S_h}{A_h}}}{3} \left( 1 + 2\lambda_h \tan \lambda_{EC_h} \right) \right]
$$

(B-11)

As the trailing edge of the horizontal tailplane root chord is fixed at the trailing edge of the local vertical tailplane chord (cf. 3.3.), the distance of the horizontal tailplane apex from the fuselage nose is:

$$
x_{apeh} = l_f + \bar{Z}_h \tan \lambda_{TE_v} - c_h
$$

(B-12)

where $\bar{Z}_h$ is the distance of the horizontal tailplane above the vertical tailplane root chord.

Substitution of (B-12) in (A-11) gives an expression similar to (B-7):

$$
\frac{1}{h_{ch}} = \frac{1}{2(1 + \lambda_h)} \left[ 1 + \frac{\sqrt{\frac{S_h}{A_h}}}{3} \left( \frac{A_h}{(1 + 2\lambda_h) \tan \lambda_{EC_h}} - 3 \right) \right]
$$

(B-13)

Analogous to the vertical tailplane, the horizontal tailplane area follows from a given tail volume coefficient:

$$
V_{OL_h} = \frac{S_{h^{1/2}}}{}
$$

(B-14)

where the moment arm is:

$$
l_h = \frac{1}{4c_h} - \frac{1}{4c}
$$

(B-15)

Substitution of (B-13) and (B-15) in (B-14) and rearranging the equation gives:
\[
F(S_h) = S_h \left\{ \frac{\frac{A_h}{3}(1 + 2\lambda_h)\tan \Lambda_c}{2(1 + \lambda_h)\sqrt{A_h}} \} + S_h \left( 1_f + \frac{Z_h \tan \Lambda_{TE_v}}{4\lambda_c} - 1 \right) \right\}
\]

\[-SbVOL_h = 0 \tag{B-16}\]

For a given vertical tailplane geometry, \(Z_h \tan \Lambda_{TE_v}\) is fixed. This requires the vertical tailplane area to be computed first.

B.4. Solving the tailplane areas using the Newton-Raphson procedure.

The Newton-Raphson procedure is widely used for solving transcendental equations as it converges quadratically.

Two cases can be considered when solving \(F(S_v)\) and \(F(S_h)\) (eqs. (B-10) and (B-16) respectively):

\[C_1 < 0\]

This condition is found for most conventional airplanes \((C_1 = -0.3\) for horizontal tailplanes and \(C_1 = -0.7\) for vertical tailplanes). The general trend of the tail volume coefficient as a function of \(S_v\) or \(S_h\) is presented in figure B1. Two solutions \((S_1^v, S_2^v)\) and \((S_1^h, S_2^h)\) are found for the tailplane area. For \(S_1^v\), a relatively small area is associated with a long momentarm, while for \(S_2^h\) the opposite is the case. Obviously, in terms of a given tail volume coefficient constraint, \(S_1^v\) is the most interesting solution.

A special condition occurs when \(\frac{C_2^3}{C_1} > 27\), in which case no solution is found.

\[C_1 > 0\]

This condition gives an increasing tail volume coefficient with increasing tailplane area (Figure B1). One solution is found for any tail volume coefficient. Henceforth, \(C_1 < 0\) is assumed.

The Newton-Raphson procedure uses the following update formula for \(F(S) = 0\) is:
\[ S_{k+1} = S_k - \frac{F(S_k)}{F'(S_k)} \]  

where \( k \) is the iteration step counter.

Figure B2 gives a graphical representation of the iteration sequence. The intersection of \( F(0) \) to \( F(S_{\text{max}}) \) with the horizontal, is taken as the initial value for \( S \):

\[ S_{\text{initial}} = -S_F \frac{F(0)}{\max F'(S_{\text{max}}) - F(0)} = \frac{3C_3}{5C_2} \]  

This insures that the procedure will converge to \( S \). The process is terminated when the improvement in \( S \) becomes less than 2.5%:

\[ |S_{k+1} - S_k| < 0.025|S_k| \]  

Experience with this procedure in SKETCH showed that an average of 2 or 3 iterations are required to solve (B-10) or (B-16).
Figure B1: Trend of tail volume coefficient with increasing tailplane area (fixed wing location).
Figure B2: Graphical representation of Newton-Raphson procedure for solving the tailplane area.

\[ C_1 < 0 \]

\[ S_{F_{\text{max}}} = \left( \frac{2}{3} \frac{C_2}{C_1} \right)^2 \]

\[ F_{\text{max}} = \frac{20}{27} \frac{C_2^3}{C_1^2} - C_3 \]

\[ S_{\text{initial}} = \frac{3C_3}{5C_2} \]
Appendix C: Directions for use.

An executable version of SKETCH is available on disk at the central graphics system, Computing Center, TH Delft. It runs under the RSX-11M operating system. Users unfamiliar with RSX-11M should consult lit. 10 for detailed information.

After the disk is loaded into the diskdrive, the following set of commands should be entered at the terminal for login and disk mount:

`>HEL userid/password`
`>MOU DK1:volumelabel`
`>ASN DK1:=SY:

An input data file must be available before SKETCH is executed. To create a new file or to update an existing one, the system editor must be used:

`>KED filename[/CR]`

For a list of available edit commands see lit. 11.

Figure C1 gives the type and format specification of the input data for each record. SKETCH utilizes free-formatted input, i.e. data items on a record should be separated by at least one blank or a comma. The record number and the location of a data item relative to the other data items on that record is essential. Real data (R) must have a decimal point, integer numbers (I) may not have a decimal point. Figure C3 gives an example of an input data file for SKETCH. A complete source listing and flow diagrams are included in lit. 1.

Drawings produced by SKETCH will appear on the Tektronix 4014 (with hardcopy unit Tektronix 4631) by default. If the user wishes to make a drawing on the on-line plotter (Tektronix 4662), the following command should be entered prior to the execution of SKETCH:

`>ASN TX:=PL:

To reset to the Tektronix 4014, enter:

`>ASN =TX:

SKETCH is executed with the command:

`>RUN $SKETCH`
The program prompts the user for the input data filename:

```
ENTER INPUT DATA FILENAME ==>
```

The input data is processed and a 3-view configuration drawing will appear on the assigned output device (Tektronix 4014 or plotter).

Subsequently, the program requests 3 rotation angles to generate a 3D wire frame model:

```
ENTER ROTATION ANGLES ABOUT X, Y AND Z-AXIS ==>
```

This prompt will be repeated in order to adjust the orientation of the model interactively. SKETCH terminates when the CTRL/Z keys are hit. Control is returned to the monitor. At this point, the input data file can be updated or SKETCH can be run again for a different input data file.

Enter:

```
>BYE
```

to dismount the disk and to leave RSX-11M.
<table>
<thead>
<tr>
<th>RECORD</th>
<th>VARIABLE NAME</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IARR(1)</td>
<td>I</td>
<td>Airplane design designation. String of upto 30 alphanumeric characters.</td>
</tr>
<tr>
<td>2</td>
<td>NPTS</td>
<td>I</td>
<td>Number of points for plotting longitudinal lines of fuselage (e.g. 200).</td>
</tr>
<tr>
<td>3-26</td>
<td>CX1(1), YZ1(1)</td>
<td>R</td>
<td>Coordinates (m) of control point I of fuselage contour lines (see figure 2). Each pair of coordinates on a new record.</td>
</tr>
<tr>
<td>27</td>
<td>C1(1)</td>
<td>R</td>
<td>Shape factors for splines in fuselage contour lines (see figure C2).</td>
</tr>
<tr>
<td>28</td>
<td></td>
<td></td>
<td>Wing parameters:</td>
</tr>
<tr>
<td></td>
<td>ANUL</td>
<td>R</td>
<td>Wing/fuselage incidence (degr)</td>
</tr>
<tr>
<td></td>
<td>AR1(1)</td>
<td>R</td>
<td>Aspect ratio</td>
</tr>
<tr>
<td></td>
<td>ARSEA(1)</td>
<td>R</td>
<td>Reference area (m^2)</td>
</tr>
<tr>
<td></td>
<td>DHDRL</td>
<td>R</td>
<td>Dihedral (degr)</td>
</tr>
<tr>
<td></td>
<td>EPS</td>
<td>R</td>
<td>Geometric twist (degr)</td>
</tr>
<tr>
<td></td>
<td>SWEEP(1)</td>
<td>R</td>
<td>Quarter-chord sweep angle (degr)</td>
</tr>
<tr>
<td></td>
<td>TAPER(1)</td>
<td>R</td>
<td>Taper ratio</td>
</tr>
<tr>
<td></td>
<td>XWING</td>
<td>R</td>
<td>Wing apex location/fuselage length ratio</td>
</tr>
<tr>
<td></td>
<td>ZWING</td>
<td>R</td>
<td>Root chord location/fuselage height ratio</td>
</tr>
<tr>
<td></td>
<td>YPTE</td>
<td>R</td>
<td>Non-swept trailing edge length/semi-span ratio</td>
</tr>
<tr>
<td></td>
<td>TCROOT(1)</td>
<td>R</td>
<td>Thickness/chord ratio at the root</td>
</tr>
<tr>
<td></td>
<td>XCT</td>
<td>R</td>
<td>Crest location/chord at the root</td>
</tr>
<tr>
<td></td>
<td>XT</td>
<td>R</td>
<td>Crest location/chord at the tip</td>
</tr>
<tr>
<td>29</td>
<td></td>
<td></td>
<td>Vertical tailplane parameters:</td>
</tr>
<tr>
<td></td>
<td>AR2(2)</td>
<td>R</td>
<td>Aspect ratio</td>
</tr>
<tr>
<td></td>
<td>SWEEP2(2)</td>
<td>R</td>
<td>Quarter-chord sweep angle (degr)</td>
</tr>
<tr>
<td></td>
<td>TAPER2(2)</td>
<td>R</td>
<td>Taper ratio</td>
</tr>
<tr>
<td></td>
<td>VOLY</td>
<td>R</td>
<td>Tail volume coefficient</td>
</tr>
<tr>
<td></td>
<td>TC ROOT2(2)</td>
<td>R</td>
<td>Thickness/chord ratio at the root</td>
</tr>
<tr>
<td></td>
<td>TCT2(2)</td>
<td>R</td>
<td>Thickness/chord tip/root ratio</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
<td>Horizontal tailplane parameters:</td>
</tr>
<tr>
<td></td>
<td>AR3(3)</td>
<td>R</td>
<td>Aspect ratio</td>
</tr>
<tr>
<td></td>
<td>SWEEP3(3)</td>
<td>R</td>
<td>Quarter-chord sweep angle (degr)</td>
</tr>
<tr>
<td></td>
<td>TAPER3(3)</td>
<td>R</td>
<td>Taper ratio</td>
</tr>
<tr>
<td></td>
<td>VOLY</td>
<td>R</td>
<td>Tail volume coefficient</td>
</tr>
<tr>
<td></td>
<td>ZNTAIL</td>
<td>R</td>
<td>Root chord location/vertical tailplane height ratio</td>
</tr>
<tr>
<td></td>
<td>TCROOT(3)</td>
<td>R</td>
<td>Thickness/chord ratio at the root</td>
</tr>
<tr>
<td></td>
<td>TCT3(3)</td>
<td>R</td>
<td>Thickness/chord tip/root ratio</td>
</tr>
<tr>
<td></td>
<td>DEHDL</td>
<td>R</td>
<td>Dihedral (degr)</td>
</tr>
<tr>
<td>31</td>
<td>NPPOD</td>
<td>I</td>
<td>Number of engines (e.g. 8)</td>
</tr>
<tr>
<td></td>
<td>KPOD</td>
<td>I</td>
<td>= 0: all engine nacelles have the same geometries</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>= 1: different engine nacelle geometries are input</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>= 0: fuselage-mounted engine</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>= 1: wing-mounted engine</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A new record for each pair of engines.</td>
</tr>
<tr>
<td>34</td>
<td></td>
<td></td>
<td>Nacelle geometry parameters:</td>
</tr>
<tr>
<td></td>
<td>DPOD</td>
<td>R</td>
<td>Nacelle diameter (m)</td>
</tr>
<tr>
<td></td>
<td>LPOD</td>
<td>R</td>
<td>Nacelle length (m)</td>
</tr>
<tr>
<td></td>
<td>PHI</td>
<td>R</td>
<td>Toe angle of nacelle (degr)</td>
</tr>
<tr>
<td></td>
<td>RPSPOD</td>
<td>R</td>
<td>Tilt angle of nacelle (degr)</td>
</tr>
<tr>
<td></td>
<td>FRP</td>
<td>R</td>
<td>Fan forebody length/fan cowling length ratio</td>
</tr>
<tr>
<td></td>
<td>DNH</td>
<td>R</td>
<td>Intake highlight diameter/nacelle diameter ratio</td>
</tr>
<tr>
<td></td>
<td>DFF</td>
<td>R</td>
<td>Fan exhaust diameter/nacelle diameter ratio</td>
</tr>
<tr>
<td></td>
<td>DGE</td>
<td>R</td>
<td>Gasgenerator exhaust diameter/nacelle diameter ratio</td>
</tr>
<tr>
<td></td>
<td>DG</td>
<td>R</td>
<td>Gasgenerator diameter/fan exhaust diameter ratio</td>
</tr>
<tr>
<td></td>
<td>LPOD</td>
<td>R</td>
<td>Fan cowling length/nacelle length ratio</td>
</tr>
</tbody>
</table>

Data items on a record must be separated by at least one blank or a comma. R = real data (with decimal point) I = integer data (without decimal point)

**Figure C1:** Type and format specification of input data for SKETCH.
<table>
<thead>
<tr>
<th>Curve</th>
<th>Description</th>
<th>$e_x$ follows from interpolation point $P_2$</th>
<th>$e_y$ follows from interpolation point $P_10$</th>
<th>$C(1)$ is direct input. If $C(1) &lt; 0$ this spline is skipped.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_1$</td>
<td>nose section</td>
<td>$e_x$ follows from interpolation point $P_2$.</td>
<td>$C(2)$ is direct input. If $C(2) &lt; 0$ then blending is performed at $P_4$.</td>
<td>$C(3)$ is direct input. If $C(3) &lt; 0$ this spline is skipped.</td>
</tr>
<tr>
<td>$S_2$</td>
<td>cockpit window</td>
<td>straight line</td>
<td>$C(4)$ is direct input. If $C(4) &lt; 0$ this spline is skipped.</td>
<td></td>
</tr>
<tr>
<td>$S_3$</td>
<td>cockpit window to upper deck</td>
<td>$C(5)$ is direct input. If $C(5) &lt; 0$ this spline is skipped.</td>
<td>$C(6)$ is direct input. If $C(6) &lt; 0$ then blending is performed at $P_{11}$.</td>
<td>$C(7)$ is direct input. If $C(7) &lt; 0$ this spline is skipped.</td>
</tr>
<tr>
<td>$S_4$</td>
<td>upper deck</td>
<td>straight line</td>
<td>$C(8)$ is direct input. If $C(8) &lt; 0$ then blending is performed at $P_{13}$.</td>
<td>$C(9)$ is direct input. If $C(9) &lt; 0$ this spline is skipped.</td>
</tr>
<tr>
<td>$S_5$</td>
<td>upper deck to mid-section</td>
<td>$C(10)$ is direct input. If $C(10) &lt; 0$ this spline is skipped.</td>
<td>$e_x$ follows from interpolation point $P_{17}$.</td>
<td></td>
</tr>
<tr>
<td>$S_6$</td>
<td>mid-section</td>
<td>straight line</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_7$</td>
<td>tail section</td>
<td>$C(11)$ is direct input. If $C(11) &lt; 0$ this spline is skipped.</td>
<td>$e_x$ follows from interpolation point $P_{18}$.</td>
<td>$C(12)$ is direct input. If $C(12) &lt; 0$ this spline is skipped.</td>
</tr>
<tr>
<td>$S_8$</td>
<td>tail cone</td>
<td>$e_x$ follows from interpolation point $P_{21}$.</td>
<td>$C(13)$ is direct input. If $C(13) &lt; 0$ this spline is skipped.</td>
<td>$C(14)$ is direct input. If $C(14) &lt; 0$ then blending is performed at $P_{22}$.</td>
</tr>
<tr>
<td>$S_9$</td>
<td>tail cone</td>
<td>$C(15)$ is direct input. If $C(15) &lt; 0$ this spline is skipped.</td>
<td>$C(16)$ is direct input. If $C(16) &lt; 0$ then blending is performed at $P_{22}$.</td>
<td></td>
</tr>
</tbody>
</table>

Figure C2: Options to shape the splines in the fuselage contour lines.
<table>
<thead>
<tr>
<th>BOEING 747-300 (EUD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td>0.3</td>
</tr>
<tr>
<td>3.37</td>
</tr>
<tr>
<td>4.45</td>
</tr>
<tr>
<td>9.38</td>
</tr>
<tr>
<td>10.14</td>
</tr>
<tr>
<td>19.36</td>
</tr>
<tr>
<td>24.27</td>
</tr>
<tr>
<td>32.72</td>
</tr>
<tr>
<td>69.13</td>
</tr>
<tr>
<td>69.74</td>
</tr>
<tr>
<td>70.28</td>
</tr>
<tr>
<td>70.51</td>
</tr>
<tr>
<td>59.20</td>
</tr>
<tr>
<td>49.93</td>
</tr>
<tr>
<td>42.40</td>
</tr>
<tr>
<td>17.45</td>
</tr>
<tr>
<td>9.22</td>
</tr>
<tr>
<td>6.14</td>
</tr>
<tr>
<td>15.36</td>
</tr>
<tr>
<td>50.54</td>
</tr>
<tr>
<td>62.37</td>
</tr>
<tr>
<td>68.21</td>
</tr>
<tr>
<td>4.00</td>
</tr>
<tr>
<td>69.50</td>
</tr>
</tbody>
</table>

| 1, -1, 1, 1, 1, -1, 1, 0.51, -1, 1, 0.51, -1, 1, 1, 0.73, 528.15 |
| 7, -3.3, 37.5, 309, 26, 21, 0, 124, 7, 0.25, 0.25 |
| 3.8, 44, 35, 1.3, 0.99, 0.12, 1 |
| 3.6, 37, 264, 1, 0.0, 0.0, 0.0 |
| 1, 4, 0 |
| 1 |
| 0.78, 404, 82 |
| 2.71, 705, 88 |
| 2.61, 5.52, 2, 0, 0.44, 0.88, 0.94, 0.71, 0.74, 0.44 |

Airplane designation (max. 30 characters)
Number of points in fuselage longitudinals
P1
P2
P3
P4
P5
P6
P7
P8
P9
P10
P11
P12
P13
P14
P15
P16
P17
P18
P19
P20
P21
P22
P23
P24

Upper fuselage contour line
Lower fuselage contour line
Side fuselage contour line
Maximum width line

Shape factors for fuselage splines
Wing geometry and location
Vertical tailplane geometry
Horizontal tailplane geometry and location
Number of engines/nacelle geometry indicator
Wing-mounted engines (first pair)
Wing-mounted engines (second pair)
Engine positional parameters (first pair)
Engine positional parameters (second pair)
Nacelle geometry

Figure C3: Example of input data file for SKETCH (Boeing 747-300).