# SKYLINE ANALYSIS WITH
# LOG DRAG

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## LEGEND OF TERMS

A = Choker angle

B = Angle between log and ground

$B_1$ = Angle between log and ground

C = Clearance between the top of the front end of the log and the ground

$C_1$ = Clearance between the carriage and the ground

$C_2$ = Carriage type

$C_5$ = Previous $C_6$

$C_6$ = Fraction of $W_4$ in $V_4$

$C_7$ = Fraction of $W_4$ in $H_4$

$C_8$ = Fractional distance from the end of log to the center of gravity

D( ) = Array of horizontal distances from the headspar to the carriage

D = Horizontal distance from the headspar to the carriage

$D_1$ = Horizontal distance from the carriage to the end of the log

$D_2$ = X coordinate of carriage with the end of the log at X(I+1)

$D_3$ = Distance from the end of the log to the point where the choker is attached

$D_5$ = Horizontal distance from the end of the log to the front of the log

E = Constant in the elliptical path equation

$E_3$ = Previous value of T

$E_4$ = Current value of T

$E_5$ = Reciprical of the fractional distance from the center of gravity of the log to the point of choker attachment divided by the distance from the end of the log to the point of choker attachment

F = Number of terms in the D( ), P( ), S( ), and V( ) arrays

$F_1$ = File yarder is to be loaded from

$F_3$ = Previous value of the function

$F_4$ = Current value of the function

$G_1$ = Minimum Y coordinate

$G_2$ = Maximum Y coordinate

$G_3$ = Maximum difference in values of the X coordinates

$G_4$ = X graph limit for plotting profiles

$G_5$ = Y graph limit for plotting profiles

$G_6$ = X offset for plotting profiles

$G_7$ = Y offset for plotting profiles

H = Vertical distance from the top of the tailspar to the top of the headspar

$H_1$ = Horizontal component of the force in line 1 at the carriage

$H_2$ = Horizontal component of the force in line 2 at the carriage

$H_3$ = Horizontal component of the force in line 3 at the carriage

$H_4$ = Horizontal component of the force in the choker at the carriage

$H_6$ = Headspar height

$H_7$ = Tailspar height

I = Terrain point number

$I_1$ = Input control parameter

$I_5$ = Integer value of headspar terrain point plus 1

$I_6$ = Integer value of tailspar terrain point

K = Constant

$K_1$ = Constant which equals Y/D

$K_2$ = Constant which equals (Y-H)/(L-D)

$K_7$ = Constant

$K_8$ = Constant

L = Span length which equals the horizontal distance from the headspar to the tailspar

$L_1$ = Length of choker from the carriage to the top of the log

$L_2$ = Distance from the choker to the end of the log

$L_3$ = Length of the log

$L_4$ = Distance from point of choker attachment to ground below the end of the log

$L_5$ = Required rigging length

M = Constant

$M_1$ = Constant

$M_2$ = Constant

$M_3$ = Constant

$M_4$ = Constant

N = Constant

$N_1$ = Number of terrain points

$N_5$ = Plot parameter which causes the log to be plotted every third point

O = Constant

P( ) = Array of slope angles

P = Slope angle

$P_1$ = Profile number and file profile is stored in

$P_5$ = Profile plot parameter

R = Type of skyline

$R_1$ = Total weight in line 1

$R_2$ = Total weight in line 2

$R_3$ = Total weight in line 3

$R_4$ = Running skyline parameter

$R_5$ = Rc/Rm

$R_6$ = Rs/Rm

$R_c$ = Distance from the center of the drum in the carriage to the dropline

$R_m$ = Distance from the center of the drum in the carriage to the mainline

$R_s$ = Distance from the center of the drum in the carriage to the slackline

S( ) = Array of terrain points

$S_1$ = Headspar terrain point

$S_2$ = Tailspar terrain point

$S_3$ = Terrain point of inner yarding limit

$S_4$ = Terrain point of outer yarding limit

$S_5$ = Terrain point step size

$S_6$ = Terrain point step size

$S_7$ = Step size between terrain points

$S_8$ = Step size between terrain points

$S_9$ = Terrain point number

T = Allowable haulback plus slackline tension

$T_0$ = Allowable slackline tension

$T_1$ = Maximum allowable skyline tension

$T_2$ = Maximum allowable haulback tension

$T_3$ = Maximum allowable mainline tension

$T_6$ = Tension in lines 1 and 2 at the carriage

$T_7$ = Tension at the headspar in line 1

$T_8$ = Tension at the headspar in line 3

$T_9$ = Tension in the mainline plus the slackline at the carriage

$T_m$ = Tension in the mainline at the carriage

$T_{ma}$ = Tension in the mainline at the headspar

$T_c$ = Tension in the choker at the carriage

$T_s$ = Tension in the slackline at the carriage

U = Coefficient of friction between the log and the ground

$U_4$ = Minimum line length

$U_5$ = Line length

$V(\ )$ = Array of the ground elevations below the carriage

$V_1$ = Vertical component of the force in line 1 at the carriage

$V_2$ = Vertical component of the force in line 2 at the carriage

$V_3$ = Vertical component of the force in line 3 at the carriage

$V_4$ = Vertical component of the force in the choker

$W$ = Haulback plus the slackline weight per foot

$W_0$ = Slackline weight per foot

$W_1$ = Skyline weight per foot

$W_2$ = Haulback weight per foot

$W_3$ = Mainline weight per foot

$W_4$ = Maximum log weight

$W_5$ = Carriage weight

$W_7$ = Maximum log weight with the skyline or haulback being limiting

$W_8$ = Maximum log weight with the mainline being limited

$X(\ )$ = Array of X coordinates

$X_1$ = X coordinate of the top of the headspar

$X_2$ = X coordinate of the top of the tailspar

$X_3$ = X coordinate of the bottom of the headspar

$X_4$ = X coordinate of the bottom of the tailspar

$X_5$ = X coordinate of the inner yarding limit

$X_6$ = X coordinate of the outer yarding limit

$X_7$ = X coordinate of the end of the log

$X_8$ = X coordinate of the carriage

$X_9$ = X coordinate of the ground below the carriage

$Y(\ )$ = Vertical distance from the top of the headspar to the carriage

$Y_1$ = Y coordinate of the top of the headspar

$Y_2$ = Y coordinate of the top of the tailspar

$Y_3$ = Y coordinate of the bottom of the headspar

$Y_4$ = Y coordinate of the bottom of the tailspar

$Y_5$ = Y coordinate of the inner yarding limit

$Y_6$ = Y coordinate of the outer yarding limit

$Y_7$ = Y coordinate of the end of the log

$Y_8$ = Y coordinate of the carriage

$Y_9$ = Y coordinate of the ground below the carriage

Y$ = Yarder name

Z( ) = Array of X and Y coordinates which are loaded from tape

# ABSTRACT

This paper describes a mathematical formulation and a computer program in basic language for analyzing the load carrying capacity of skyline systems using the effects of log drag. The actual log and ground geometry are used in the analysis of the payload capacities for standing, live and running skylines. The paper uses an example problem to show the effects of the various parameters used in computing payload capacity using the effects of log drag (choker length, log length, log to ground clearance, point of choker attachment, center of gravity of the log, coefficient of friction, and type of carriage).

The method described in this paper was compared with an existing method which calculates skyline payloads for a fully suspended load. It was found that when logs have one end suspension, there can be considerable difference in the payloads calculated by the two methods.

# INTRODUCTION

An important step in planning skyline logging systems is the determination of the load-carrying capacity of the skyline system while anchored in a specific geometry and operating over a specific terrain. Several methods are now available to determine the load-carrying capacity of this type of system: graphical-tabular handbook approaches and mathematical solutions using hand held, desk top, and large computer systems. However, until recently none of these systems took into account the effect of log drag and the effect of the actual log to ground geometry. Recently, Gary Falk (6) developed a series of HP 67 programs which consider the effect of the actual log to ground geometry.

Most of the methods currently used assume a fully suspended load. The Skyline Analysis Program on the HP 9830 assumes a fully suspended load and increases the net load by 50 percent for a dragging log.

The effects of the forces due to log drag on the skyline and mainline depend on the angle the log makes with the ground, length of the log, length of the choker, carriage clearance, ground slope, weight of the turn, log diameter, point of choker attachment and the coefficient of friction between the log and the ground. Carson (2) developed equations for using the effects of log drag in determining the load carrying capacity of running skylines. The equations developed by Carson determine the forces at the carriage for a given angle between the log and the ground. The equations cannot be applied directly to a standing skyline where the angle the log makes with the ground varies as the load is brought in.

With a standing skyline, the length of the skyline is fixed during the yarding cycle. The length of the skyline is often fixed at a length such that the log will have at least one end suspended at all points. This is done to eliminate the soil displacement damage caused by the plowing of the front end of the log. Once the length of the skyline is fixed, the angle the log makes with the ground along the skyline road varies according to the ground slope, length of the log, length of the choker and carriage clearance.

Desk top computer systems, such as the HP 9830, HP 9845, and the Techtronics 4051, provide one of the easiest and fastest methods for entering profile data and determining the load carrying capacity of skylines. These systems have the ability to enter profile data from a digitizer, keyboard, files, X, Y coordinates, or slope, % slope data. The profile data can be stored for later use, analyzed, and plotted with these systems.

This paper describes a mathematical formulation, a computer program written in basic placed on the HP 9830 and the effects of the various parameters in using log drag for determining the load carrying capacity of live, standing and running skylines.

## OBJECTIVES

The purpose of this study is to analyze the effects of using log drag for determining the load carrying capacity of live, running and standing skylines, and to develop a working model on the HP 9830 for determining the payload capacity of these skyline systems with the effects of log drag included in the model. The specific objectives will be as follows:

1. Develop a computer program written in basic and placed on the HP 9830 which will determine the load carrying capacity for a live, standing, and running skyline system given; the allowable mainline tension, the allowable skyline tension, log to ground geometry, the log length, choker length, log to ground coefficient of friction, yarder specifications, ground profile and cable system geometry.
2. Determine individually the effects of the various parameters used in the model (choker length, log length, log to ground clearance, point of choker attachment, center of gravity of the log, coefficient of friction, and type of carriage), and their effect on the load carrying capacity, mainline tensions, and skyline tensions.
3. Compare the results obtained using the HP 9830 Skyline Analysis Program with the results from the Skyline Analysis Program with Drag developed in this paper.

# MATHEMATICAL FORMULATIONS

The symbols used in the following formulations are all described in the Legend of Terms. The terms used are all terms which could be programmed into the HP 9830 and the equations shown are the ones used in the computer programs.

## Log Drag for a Live and a Running Skyline

For the purposes of this paper a live skyline will be defined as a system having two lines; a skyline and a mainline, where the skyline length is varied to maintain a constant log to ground clearance (C) as shown in Figure (1). A running skyline is a system where the haulback line runs through a sheave in the carriage, through a block at the tailspar, and is then connected to the carriage. It has one or two additional lines, a mainline and a slackpulling line, which run from the headspar to the carriage. In a running skyline the haulback line length will vary to maintain a constant log to ground angle ($B_1$).

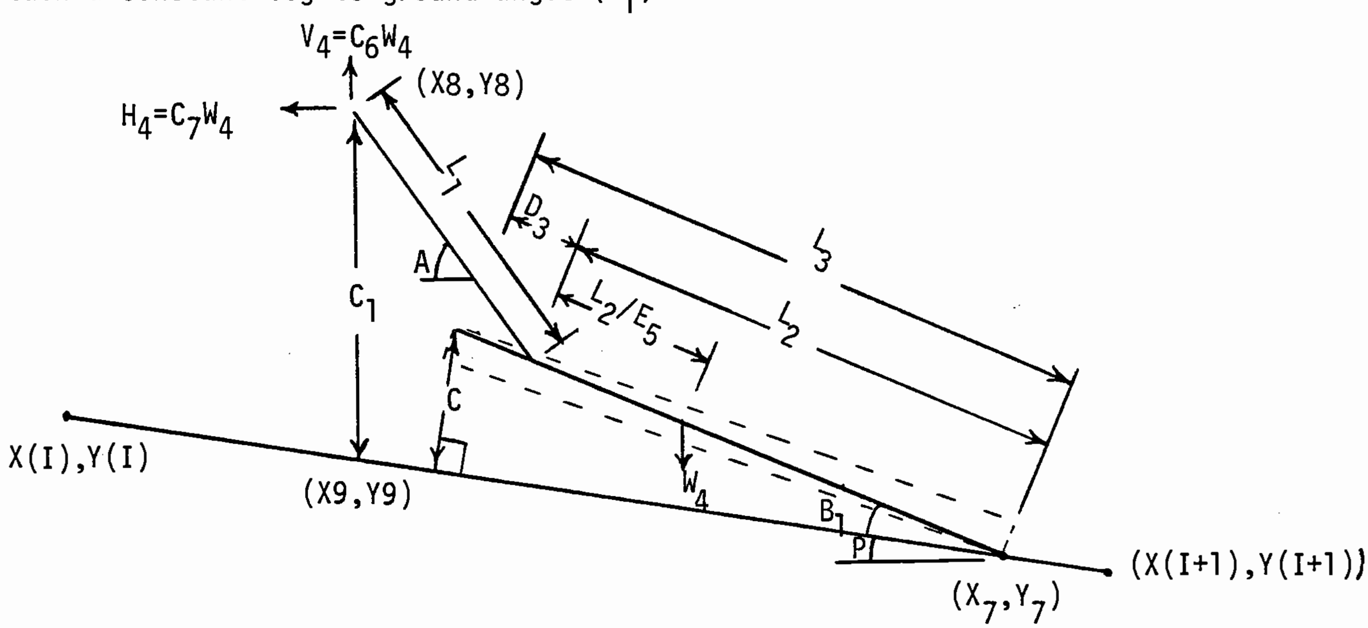



Figure 1. Log to Ground Geometry for a Running and a Live Skyline.

The following values are known:

C, P, X(I), Y(I), $X_7$, $Y_7$, X(I+1), Y(I+1), L3, L2, E5, L1

We want to find: $C_6$, $C_7$, $C_1$, $X_8$, $Y_8$

For the geometry shown in Figure 1, Carson (2) developed the following equations for determining the horizontal and vertical forces at the carriage due to a dragging log:

$$H_4 = W_4(U\cos P+\sin P)\left(\frac{\cos(P+B_1)/E_5}{\cos B_1+U\sin B_1}\right) \quad (1)$$

$$V_4 = W_4[1+(U\sin P-\cos P)]\left(\frac{\cos(P+B_1)/E_5}{\cos B_1+U\sin B_1}\right) \quad (2)$$

However, we wish to find $C_6$, $C_7$, $C_1$, $X_8$, $Y_8$ so let:

$$C_7 = H_4/W_4 \quad (3)$$

$$C_6 = V_4/W_4 \quad (4)$$

$$K = \cos(P+B)/[E_5(\cos(B_1)+U\sin(B_1))] \quad (5)$$

Then:

$$P = \mathrm{Tan}^{-1}[(Y(I)-Y(I+1)]/[X(I+1)-X(I)] \quad (6)$$

$$B_1 = \sin^{-1}(C/L_3) \quad (7)$$

$$E_5 = L_2/(L_2-L_3/2) \quad (8)$$

$$C_7 = [U\cos(P)+\sin(P)]K \quad (9)$$

$$C_6 = [1+(U\sin(P)-\cos(P)]K \quad (10)$$

$$A = 90-\tan^{-1}(C_7/C_6) \quad (11)$$

$$X_7 = X_8+L_2\cos(P+B_1)+L_1\cos(A) \quad (12)$$

$$Y_8 = Y_7+L_2\sin(P+B_1)+L_1\sin(A) \quad (13)$$

$$Y_9 = Y_7+(X_9-X_7)\sin(P) \quad (14)$$

$$C_1 = Y_8-Y_9 \quad (15)$$

With this set of equations the geometry and fraction of the log weight that is in the vertical and horizontal components of the choker at the carriage can be determined for a given log length, choker length, point of choker attachment, location of the center of gravity, and the ground slope.

Log Drag for a Standing Skyline

For a standing skyline the log to ground clearance (C) is unknown, but the carriage clearance $C_1$ can be found from the elliptical load path equations, the skyline length, and the cable system and ground geometry. So, referring to Figure 1, we are given: $C_1$, P, X(I), Y(I), X(I+1), Y(I+1), $X_8$, $Y_8$, $X_9$, $Y_9$, $L_2$, $L_3$, $E_5$, $L_1$.

We want to find: $C_6$, $C_7$, $B_1$, A

Referring to Figure 2:

$$C' = C_1 - L_1 \sin(A) + L_1 \cos(A) \tan(P) \tag{16}$$

$$A = 90 - \tan^{-1}(C_7/C_6) \tag{17}$$

Then from the law of sines and Figure 2:

$$\frac{L_2}{\sin(90+P)} = \frac{C'}{\sin(B_1)} \tag{18}$$

Substituting in equation (16) and simplifying yields:

$$\frac{L_2}{\cos(P)} = \frac{C_1 - L_1 \sin(A) + L_1 \cos(A) \tan(P)}{\sin(B_1)} \tag{19}$$

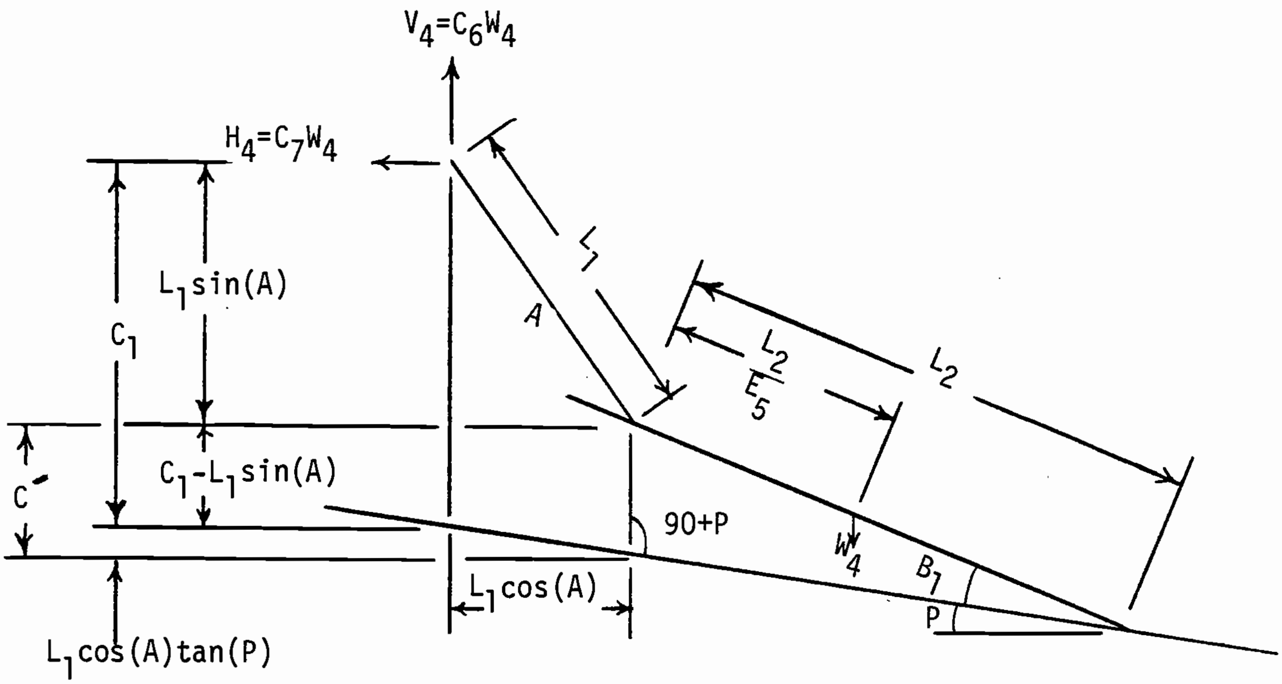



Figure 2. Log Geometry for a Standing Skyline.

Solving for $B_1$:

$$B_1 = \sin^{-1}\left[\frac{\cos(P)}{L_2}\,(C_1+L_1(\cos(A)\tan(P)-\sin(A))\right] \tag{20}$$

Now, the following equations can be used to solve for $B_1$, $C_6$, $C_7$ and A:

$$B_1 = \sin^{-1}\left[\frac{\cos(P)}{L_2}\,(C_1+L_1(\cos(A)\tan(P)-\sin(A))\right] \tag{20}$$

$$K = \cos(P+B_1)/(E_5(\cos(B_1)+U\sin(B_1))) \tag{5}$$

$$C_7 = (U\cos(P)+\sin(P))K \tag{9}$$

$$C_6 = (1+(U\sin(P)-\cos(P))K \tag{10}$$

$$A = 90-\tan^{-1}(C_7/C_6) \tag{17}$$

To solve for $C_6$ and $C_7$ these equations are transcendental (cannot be manipulated algebraically for direct solution), so an iterative type solution is needed. First, for an initial guess of $B_1$ we can assume $L_1$

and $L_2$ are a straight line as shown in Figure 3.

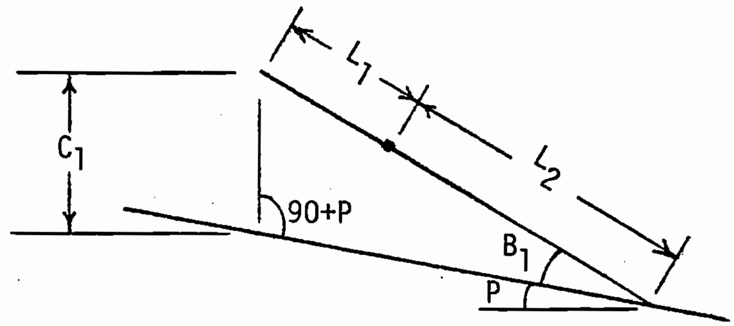



Figure 3. Geometry for an initial guess of $B_1$.

Using the law of sines for the geometry of Figure 3, we obtain:

$$\frac{L_1+L_2}{\sin(90+P)} = \frac{C_1}{\sin(B_1)} \tag{21}$$

$$B_1 = \sin^{-1}[C_1\sin(90+P)/(L_1+L_2)] \tag{22}$$

The iterative procedure is to first use equation (22) to arrive at an initial guess of $B_1$. Then this value is used in equations (5), (9) and (10) to solve for $C_7$ and $C_6$. Using these values of $C_6$ and $C_7$, the value of A can be found from equation (17). This value can then be used in equation (20) to solve for a new value of $B_1$.

Then the new value of $B_1$ can be used in equations (5), (9) and (10) to solve for $C_7$ and $C_6$. This process is then continued until the value of $C_6$ changes by less than 0.001. This is not a conventional type iterative procedure, but for this problem it tends to converge very rapidly.

Live and Standing Skyline Loads and Line Tensions

The following analysis uses a rigid link assumption for the lines, and neglects line stretch. Figure 4 below shows the cable system geometry for this problem.

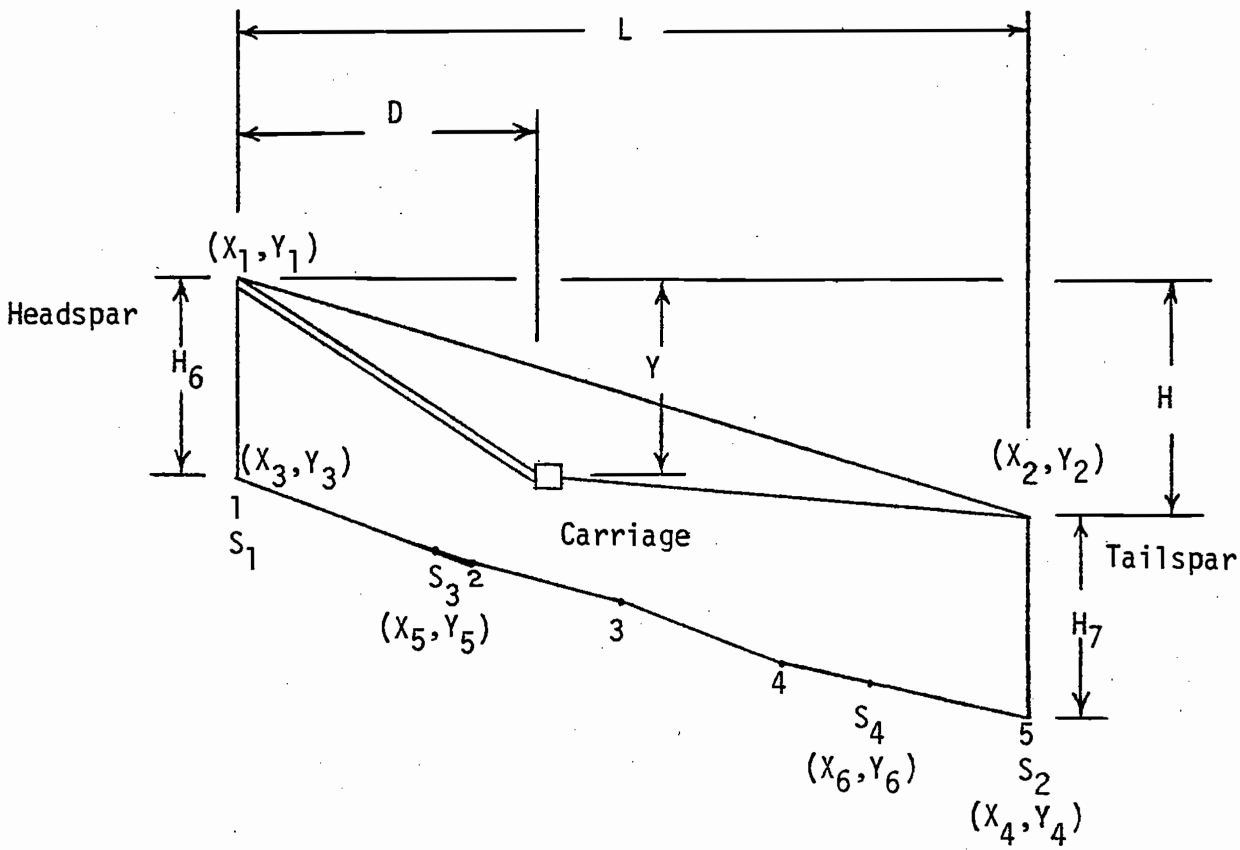



Figure 4. Cable System Geometry.

Figure 5 shows the geometry and forces acting on each line segment for this problem.

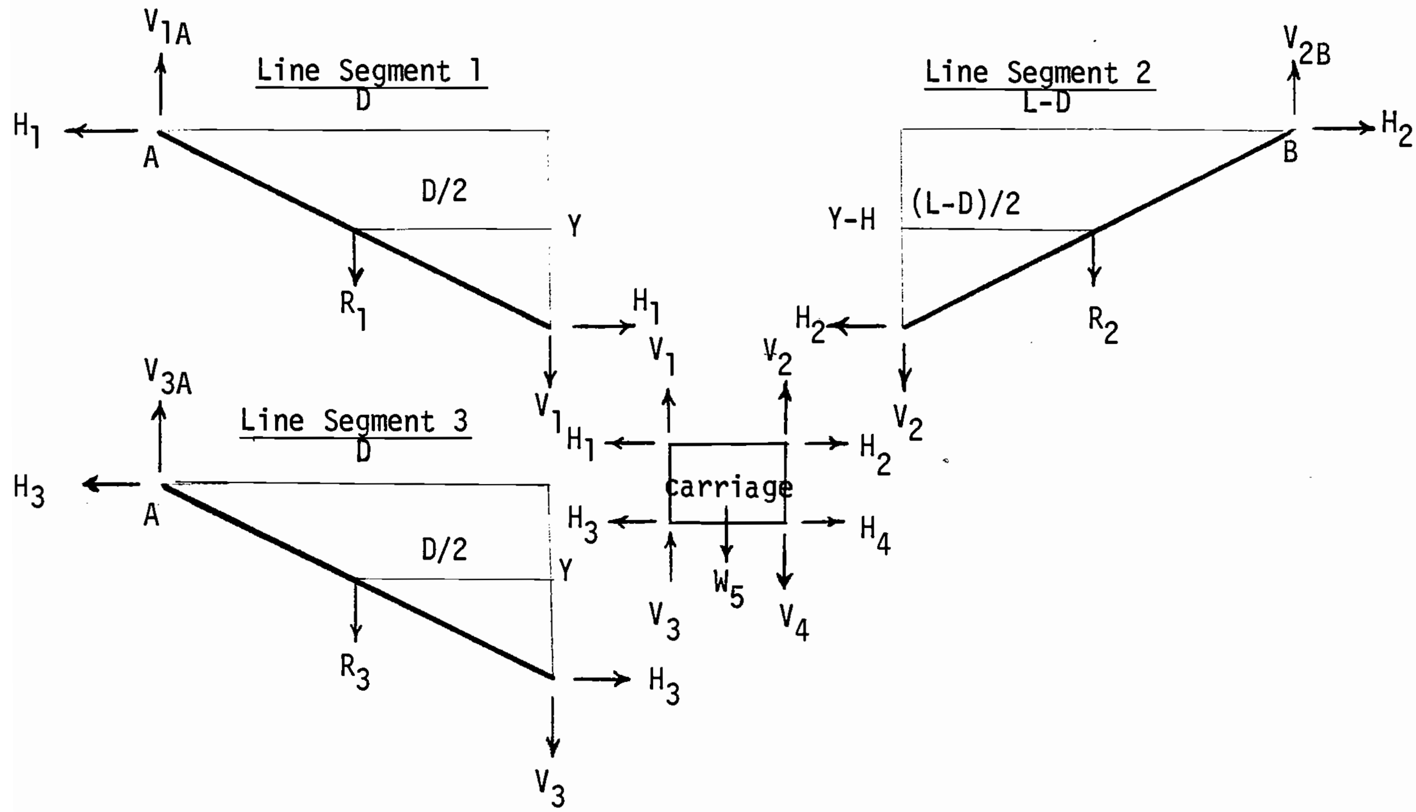



Figure 5. Free Body Diagram for a Standing and Live Skyline.

For each line segment the moments can be taken about the upper end. Since the system is assumed to be in static equilbrium, there has to be a moment force balance for each line segment. The following three equations are then obtained:

$\Sigma M_A=0 \quad V1 = H_1 \ (Y/D) - R_1/2$ (23)

$\Sigma M_B=0 \quad V2 = H_2 \ [(Y-H)/L-D] - R_2/2$ (24)

$\Sigma M_A=0 \quad V3 = H_3 \ (Y/D) - R_3/2$ (25)

The carriage is also assumed to be in static equilbrium, so the horizontal and vertical forces at the carriage must balance. The equations for the carriage force balance are:

$$\Sigma F_x=0 \qquad H_3 = -H_1 + H_2 + H_4 \tag{26}$$

$$\Sigma F_y=0 \qquad V_1 + V_2 + V_3 = W_5 + V_4 \tag{27}$$

Let:

$$K_1 = Y/D \tag{28}$$

$$K_2 = (Y-H)/(L-D) \tag{29}$$

Substituting equations (23), (24), (25), (28), and (29) into equation (27):

$$H_1K_1-R_1/2+H_2K_2-R_2/2+H_3K_1-R_3/2 = W_5+V_4 \tag{30}$$

Now using equation (26) to substitute in for $H_3$:

$$H_1K_1-R_1/2+H_2K_2-R_2/2-H_1K_1+H_2K_1+H_4K_1-R_3/2 = W_5+V_4 \tag{31}$$

Reducing:

$$H_2(K_1+K_2)+H_4K_1-(R_1+R_2+R_3)/2 = W_5+V_4 \tag{32}$$

Solving for $H_2$ yields:

$$H_2 = \frac{(R_1+R_2+R_3)/2+W_5+V_4-H_4K_1}{K_1+K_2} \tag{33}$$

In the above equations $R_1$, $R_2$ and $R_3$ are the forces due to the weight of the cable in each line segment. These forces can be found from the following equations:

$$R_1 = W_1\sqrt{D^2 + Y^2} \tag{34}$$

$$R_2 = W_1 \sqrt{(L-D)^2 + (Y-H)^2} \quad (35)$$

$$R_3 = W_3 \sqrt{D^2 + Y^2} \quad (36)$$

The skyline passes under sheaves in the carriage. Assuming a frictionless sheave, when a line passes under a sheave, the tensions in the line on both sides of the sheave are equal. So for lines 1 and 2, the tension in the cables at the carriage are equal. From this relationship the following equations can be formulated:

$$T_6 = \sqrt{V_1^2 + H_1^2} = \sqrt{V_2^2 + H_2^2} \quad (37)$$

or

$$T_6^2 = V_1^2 + H_1^2 = V_2^2 + H_2^2 \quad (38)$$

From equation (33) the value of $H_2$ can be found and using the relationship between $H_2$ and $V_2$ from equation (24), the value of $T_6$ can be found from the following equation:

$$T_6 = \sqrt{H_2^2 + (H_2K_2 - R_2/2)^2} \quad (39)$$

Reducing yeilds:

$$T_6 = \sqrt{H_2^2(1+K_2^2) - R_2H_2K_2 + R_2^2/4} \quad (40)$$

Once the value of $T_6$ is found the value of $H_1$ can be found by using equation (38) and the relationship between $V_1$ and $H_1$ from equation (23) as follows:

$$T_6^2 = V_1^2 + H_1^2 = H_1^2 + (H_1K_1 - R_1/2)^2 \quad (41)$$

Reducing yields:

$$H_1^2(1+K_1^2) - H_1K_1R_1 + R_1^2/4 - T_6^2 = 0 \qquad (42)$$

Since $H_1$ is the only unknown in this equation, the solution can be found from the quadratic equation as follows:

Let:

$$M = 1+K_1^2 \qquad (43)$$

$$N = -K_1R_1 \qquad (44)$$

$$O = R_1^2/4-T_6^2 \qquad (45)$$

Then:

$$H_1 = \frac{-N + \sqrt{N^2-4MO}}{2M} \qquad (46)$$

The value of $H_4$ can be found from the log drag equations and the values of $H_1$ and $H_2$ can be found from the previously formulated equations. Once these values are found the value of $H_3$ can be found from equation (26).

Now the tension in the lines 1 and 3 at the headspar can be found using equations (23), (25), (28), and (29) as follows:

$$T_6 = \sqrt{V_1^2+H_1^2} = \sqrt{(H_1K_1-R_1/2)^2+H_1^2} \qquad (48)$$

$$T_M = \sqrt{V_3^2+H_3^2} = \sqrt{(H_3K_1-R_3/2)^2+H_3^2} \qquad (49)$$

Then:

$$T_7 = T_6+W_1Y = \sqrt{(H_1K_1-R_1/2)^2+H_1^2} + W_1Y \qquad (50)$$

$$T_8 = T_M+W_3Y = \sqrt{(H_3K_1-R_3/2)^2+H_3^2} + W_3Y \qquad (51)$$

The relationships $T_7 = T_6 + W_1Y$ and $T_8 = T_M + W_3Y$ are from the catenary equation. This is one of the more simple and easy to use relationships from the catenary equations. This relationship will be used to convert tensions from the carriage to the headspar and from the headspar to the carriage. It will be used to convert the magnitude of the force, and the rigid link equations will be used to determine the direction of the force.

The previously formulated equations assumed the log weight was known. If the log weight is known, then from the previously formulated equations the mainline and skyline tensions can be found. However, it is useful to know what log weight will cause the mainline or skyline to be at its maximum allowable tension.

The following analysis is a method of determining the maximum allowable load which will cause the skyline to be at its maximum allowable tension.

First, assuming the skyline is at its maximum allowable load, then the value of $H_2$ can be found using equation (24) in the following analysis:

$$T_6 = T_1 - W_1Y \tag{53}$$

$$T_6^2 = H_2^2 + V_2^2 = H_2^2 + (H_2K_2-R_2/2)^2 = (T_1-W_1Y)^2 \tag{54}$$

Reducing yields:

$$H_2^2(1+K_2^2)-H_2K_2R_2 + R_2^2/4 - (T_1-W_1Y)^2 = 0 \tag{55}$$

To solve for $H_2$ the quadratic equation must be used as follows:

Let:

$$M = 1+K_2^2 \tag{56}$$

$$N = -K_2R_2 \tag{57}$$

$$O = R_2^2/4 - (T_1-W_1Y)^2 \tag{58}$$

Then:

$$H_2 = \frac{-N + \sqrt{N^2-4MO}}{2M} \tag{59}$$

If the value of $H_2$ is known, equations (3) and (4) can be used to substitute for the value of $H_4$ and $V_4$ in equation (33) and then the value of $W_7$ can be solved for in equation (33) as follows:

$$H_2 = \frac{(R_1+R_2+R_3)/2 + W_5 + C_6W_7 - C_7W_7K_1}{K_1+K_2} \tag{60}$$

Solving for $W_7$ yields:

$$W_7 = \frac{H_2(K_2+K_1) - W_5 - (R_1+R_2+R_3)/2}{(C_6-C_7K_1)} \tag{61}$$

With the above equations, the log weight can be found which causes the skyline to be at its maximum allowable tension. However, in some cases the mainline will be the limiting factor in determining the maximum log weight. The following analysis is a method of determing the log weight which will cause the mainline to be at its maximum allowable load.

From equation (26):

$$H_1 = H_2 - H_3 + H_4 \tag{62}$$

$$H_1^2 = H_2^2 + H_3^2 + H_4^2 - 2H_4H_3 + 2H_4H_2 - 2H_3H_2 \tag{63}$$

Then from equations (38), (23) and (24):

$$V_1^2 + H_1^2 = V_2^2 + H_2^2 \tag{64}$$

$$(H_1K_1-R_1/2)^2 + H_1^2 = (H_2K_2-R_2/2)^2 + H_2^2 \quad (65)$$

$$H_1^2(1+K_1^2) - H_1K_1R_1 + (R_1^2-R_2^2)/4 - H_2^2(1+K_2^2) + H_2K_2R_2 = 0 \quad (66)$$

Substituting the values of $H_1$ and $H_1^2$ from equations (62) and (63) into equation (66) yields:

$$H_2^2(K_1^2-K_2^2) + H_2(2H_4(1+K_1^2) - 2H_3(1+K_1^2) - K_1R_1+K_2R_2)$$
$$+ H_3^2(1+K_1^2) + H_4^2(1+K_1^2) - 2H_4H_3(1+K_1^2) + H_3K_1R_1$$
$$- H_4K_1R_1 + (R_1^2-R_2^2)/4 = 0 \quad (67)$$

Now let:

$$V_4 = C_6W_8 \quad (68)$$

$$H_4 = C_7W_8 \quad (69)$$

$$M_1 = \frac{W_5 + (R_1+R_2+R_3)/2}{K_1+K_2} \quad (70)$$

$$M_2 = (C_6-C_7K_1)/(K_1+K_2) \quad (71)$$

$$M_3 = K_1^2 - K_3^2 \quad (72)$$

$$M_4 = 1 + K_1^2 \quad (73)$$

Substituting (68), (69), (70), and (71) into equation (33) gives:

$$H_2 = M_1 + M_2W_8 \quad (74)$$

$$H_2^2 = M_1^2 + 2M_2M_1W_8 + M_2^2W_8^2 \quad (75)$$

Substituting equations (68), (69), (72), (73), (74), and (75), into equation (67) yields:

$$(M_1^2 + 2M_2M_1W_8 + M_2^2W_8^2)M_3 + (M_1+M_2W_8)(2C_7W_8M_4 - 2H_3M_4$$
$$- K_1R_1 + K_2R_2) + H_3^2M_4 + C_7^2W_8^2M_4^2 - 2C_7W_8H_3M_4 + H_3K_1R_1$$
$$- C_7W_8K_1R_1 + (R_1^2 - R_2^2)/4 = 0 \qquad (76)$$

Simplifying yields:

$$W_8^2(M_2^2M_3 + 2M_2M_4C_7 + C_7^2M_4) + W_8(M_2(2M_3M_1 - 2H_3M_4 - K_1R_1$$
$$+ K_2R_2) + 2C_7M_4(M_1 - H_3) - C_7K_1R_1) + M_1(M_1M_3 - 2H_3M_4 - K_1R_1$$
$$+ K_2R_2) + H_3(H_3M_4 + K_1R_1) + (R_1^2 - R_2^2)/4 = 0 \qquad (77)$$

To solve for $W_8$ the quadratic formula must be used as follows:

Let:

$$M = M_2^2M_3 + 2M_2M_4C_7 + C_7^2M_4 \qquad (78)$$

$$N = M_2(2M_3M_1 - 2H_3M_4 - K_1R_1 + K_2R_2) + 2C_7M_4(M_1-H_3) - C_7K_1R_1 \qquad (79)$$

$$O = M_1(M_1M_3 - 2H_3M_4 - K_1R_1 + K_2R_2) + H_3(H_3M_4+K_1R_1) + (R_1^2-R_2^2)/4 \qquad (80)$$

Then:

$$W_8 = \frac{-N + \sqrt{N^2 - 4MO}}{2M} \qquad (81)$$

The value of $H_3$ to be used in the above equations can be found using equation (25) in the following analysis:

$$T_M^2 = V_3^2 + H_3^2 = (H_3K_1-R_3/2)^2 + H_3^2 = (T_3-W_3Y)^2 \qquad (82)$$

Reducing yields:

$$H_3^2(K_1^2+1) - H_3K_1R_3 + R_3^2/4 - (T_3-W_3Y)^2 \qquad (84)$$

The solution to equation (84) can be found using the quadratic formula as follows:

Let:

$$M = 1+K_1^2 \qquad (85)$$

$$N = -K_1R_3 \qquad (86)$$

$$O = R_3^2/4 - (T_3-W_3Y)^2 \qquad (87)$$

Then:

$$H_3 = \frac{-N + \sqrt{N^2-4MO}}{2M} \qquad (88)$$

The solution procedure for finding the maximum allowable log weight, is to find the maximum log weight with the skyline being limited and then find the maximum log weight with the mainline being limited. The smaller of these values is then the maximum log weight. The limiting line will then be at its maximum allowable tension and the tension in the other line can be found from the formulas which give the tensions in the lines for a given log weight.

## Running Skyline Loads and Line Tensions

The analysis method for a running skyline is essentially the same as for a standing and live skyline, only in place of line 2 are two lines with equal tensions. The mathematical formulation shown here for a running skyline will be reduced, just showing the essential equations and analysis. For more details on the analysis refer to the standing and live skyline analysis which is essentially the same with only a few changes in each equation. The cable system geometry for a running skyline is the same as shown in Figure 4. The geometry and forces acting on each line segment are as shown in Figure 6.

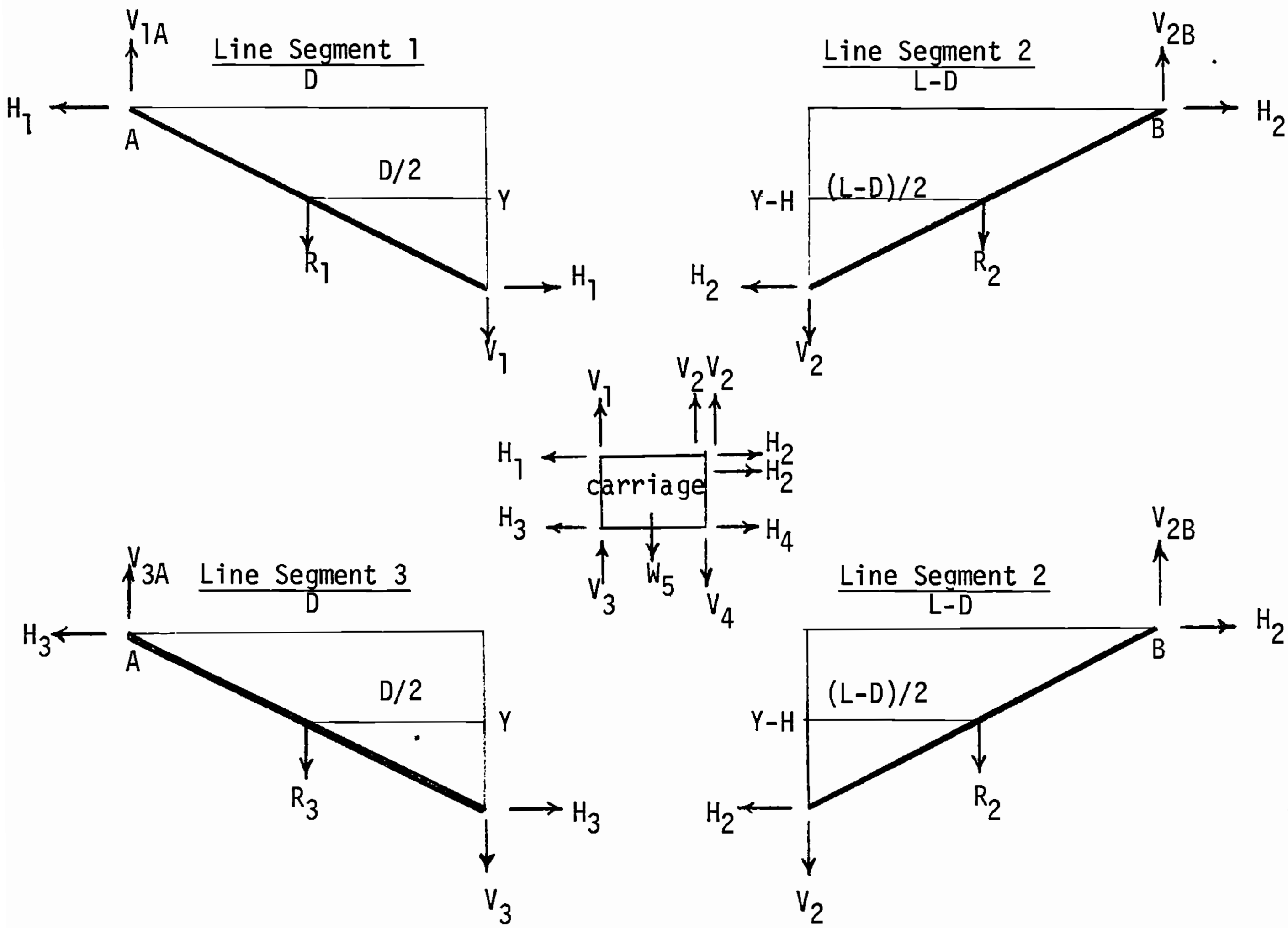



Figure 6. Free Body Diagram for a Running Skyline.

For a running skyline, the equations for the moment and vertical force balance for each line segment remain essentially the same as equations (23), (24), (25), (28), and (29). These equations are as follows:

Let:

$$K_1 = Y/D \tag{89}$$

$$K_2 = (Y-H)/(L-D) \tag{90}$$

Then:

$$\Sigma M_A = 0 \qquad V_1 = H_1K_1 - R_1/2 \tag{91}$$

$$\Sigma M_B = 0 \qquad V_2 = H_2K_2 - R_2/2 \tag{92}$$

$$\Sigma M_A = 0 \qquad V_3 = H_3K_1 - R_3/2 \tag{93}$$

The equations for the carriage force balance are the following:

$$\Sigma Fx = 0 \qquad 2H_2 + H_4 - H_1 + H_3 = 0 \tag{97}$$

$$\Sigma Fy = 0 \qquad V_1 + 2V_2 - V_3 - W_5 - V_4 = 0 \tag{98}$$

Using these equations, the following equation for $H_2$ can be formulated:

$$H_2 = \frac{W_5 + V_4 + (R_1+2R_2+R_3)/2 - H_4K_1}{2(K_1+K_2)} \tag{99}$$

The equation for $R_1$, $R_2$ and $R_3$ are only changed by substituting for the different line weights as follows:

$$R_1 = W_2 \sqrt{D^2+Y^2} \tag{100}$$

$$R_2 = W_2 \sqrt{(L-D)^2+(Y-H)^2} \tag{101}$$

$$R_3 = W \sqrt{D^2+Y^2} \tag{102}$$

The haulback on a running skyline also passes over a sheave in the carriage, so assuming a frictionless sheave, the tensions in lines 1 and 2 at the carriage will be equal which are also equal to the tension in line 2 at the carriage. From this relationship, the following equations can be formulated:

$$T_6 = \sqrt{V_1^2+H_1^2} = \sqrt{V_2^2+H_2^2} \tag{103}$$

$$T_6^2 = V_1^2 + H_1^2 = V_2^2 + H_2^2 \tag{104}$$

Substituting for the value of $V_2$ from equation (92) into equation (103) yields:

$$T_6 = \sqrt{H_2^2 + (H_2K_2-R_2/2)^2} \tag{105}$$

Once the value of $T_6$ is found, the following equation can be formulated from equations (104) and (91) to find the value of $H_1$:

$$H_1^2(1+K_1^2) - H_1K_1R_1 + R_1^2/4 - T_6^2 = 0 \tag{106}$$

The solution to this equation for $H_1$ can be found from the quadratic formula as follows:

Let:

$$M = 1+K_1^2 \tag{107}$$

$$N = -K_1R_1 \tag{108}$$

$$O = R_1^2/4 - T_6^2 \tag{109}$$

Then:

$$H_1 = \frac{-N + \sqrt{N^2-4MO}}{2M} \tag{110}$$

Once the values of $H_1$ and $H_2$ are found from equations (99) and (110), the value of $H_3$ can be found from equation (97). When the values of $H_1$ and $H_3$ are known, the tensions in lines 1 and 3 at the headspar can be found from the following equation:

$$T_7 = \sqrt{H_1^2 + (H_1K_1 - R_1/2)^2} + W_1Y \tag{111}$$

$$T_8 = \sqrt{H_3^2 + (H_3K_1 - R_3/2)^2} + W_3Y \tag{112}$$

The previously formulated equations are for determining the haulback and mainline tensions for a given log weight.

The following analysis is for determining the maximum allowable log weight with the haulback being limited by its maximum allowable load:

$$T_6 = T_2 - W_1Y \tag{113}$$

$$T_6^2 = H_2^2 + V_2^2 = H_2^2 + (H_2K_2 - R_2/2)^2 = (T_2 - W_2Y)^2 \tag{114}$$

Reducing yields:

$$H_2^2(1+K_2^2) - H_2K_2R_2 + R_2^2/4 - (T_2 - W_2Y)^2 = 0 \tag{115}$$

To solve for $H_2$ the quadratic formula must be used as follows:

Let:

$$M = 1+K_2^2 \tag{116}$$

$$N = -K_2R_2 \tag{117}$$

$$0 = R_2^2/4 - (T_2 - W_2Y)^2 \tag{118}$$

Then:

$$H_2 = \frac{-N + \sqrt{N^2-4MO}}{2M} \tag{119}$$

Once the value of $H_2$ is known, equations (2) and (3) can be used to substitute in for the values of $V_4$ and $H_4$ and the resulting equation can be solved for $W_7$ yielding the following equation:

$$W_7 = \frac{2H_2(K_2+K_1) - W_5 - (R_1+2R_2+R_3)/2}{C_6-C_7K_1} \tag{120}$$

With the above equation, the log weight can be found which will cause the haulback to be at its maximum allowable tension. However, with a running skyline, the mainline will often be the limiting factor in determining the maximum log weight. The following analysis is a method of determining the log weight which will cause the mainline to be at its maximum allowable load.

First, by substituting equations (91), (92) and (97) into equation (104) and simplifying yields:

$$\begin{aligned} &H_2^2(4K_1^2-K_2^2+3) + 2H_2(2H_4(1+K_1^2)-2H_3(1+K_1^2)+K_1R_1+K_2R_2/2) \\ &+H_3^2(1+K_1^2)+H_4^2(1+K_1^2)-2H_4H_3(1+K_1^2)+H_3K_1R_1-H_4K_1R_1 \\ &+(R_1^2-R_2^2)/4 = 0 \end{aligned} \tag{121}$$

Then let:

$$V_4 = C_6W_8 \tag{122}$$

$$H_4 = C_7W_8 \tag{123}$$

$$M_1 = \frac{(R_1+2R_2+R_3)/2 + W_5}{2(K_1+K_2)} \tag{124}$$

$$M_2 = \frac{C_6-C_7K_1}{2(K_1+K_2)} \tag{125}$$

$$M_3 = 4K_1^2 - K_2^2 + 3 \tag{126}$$

$$M_4 = 1 + K_1^2 \tag{127}$$

Substituting equations (122), (123), (124), and (125) into equation (99) yields:

$$H_2 = M_1 + M_2W_8 \tag{128}$$

$$H_2^2 = M_1^2 + 2M_2M_1W_8 + M_2^2W_8^2 \tag{129}$$

Substituting equations (122), (123), (126), (127), (128), and (129), into equation (121) and simplifying yields:

$$W_8^2(M_2^2M_3+4M_2M_4C_7+C_7^2M_4) + W_8(M_1(M_1M_3-4H_3M_4-2K_1R_1+K_2R_2)) \\ +H_3(H_3M_4+K_1R_1) + (R_1^2-R_2^2)/4 = 0 \tag{130}$$

To solve for $W_8$ in this equation the quadratic formula can be used as follows:

Let:

$$M = M_2^2M_3 + 4M_2M_4C_7 + C_7^2M_4 \tag{131}$$

$$N = M_2(2M_3M_1-4H_3M_4-2K_1R_1+K_2R_2) + 2C_7M_4(2M_1-H_3) - C_7K_1R_1 \qquad (132)$$

$$O = M_1(M_1M_3-4H_3M_4-2K_1R_1+K_2R_2) + H_3(H_3M_4+K_1R_1) + (R_1^2-R_2^2)/4 \qquad (133)$$

Then:

$$W_8 = \frac{-N + \sqrt{N^2-4MO}}{2M} \qquad (134)$$

The value of $H_3$ to be used in the above equations can be found using equation (93) as follows:

$$T_M^2 = V_3^2 + H_3^2 = (H_3K_1-R_3/2)^2 + H_3^2 = (T_3-W_3Y)^2 \qquad (135)$$

Reducing yields:

$$H_3^2(K_1^2+1) - H_3K_1R_3 + R_3^2/4 - (T_3-W_3Y)^2 = 0 \qquad (137)$$

The solution to equation (137) can be found using the quadratic formula as follows:

$$H_3 = \frac{K_1R_3 + \sqrt{K_1^2R_3^2-4M_4(R_3^2/4-(T-WY)^2)}}{2M_4} \qquad (139)$$

The solution procedure for finding the maximum allowable log weight is to find the maximum log weight with the haulback being limited and then find the maximum log weight with the mainline being limited. The smaller of these values is then the maximum log weight. The limiting line will then be at its maximum allowable tension and the tension in the other line can be found from the formulas which give the tensions in the lines for a given log weight.

## Standing Skyline Length and Carriage Clearance

A standing skyline has a fixed line length. For this analysis it is assumed that this line length is fixed such that the log will have a specified minimum amount of one and suspension at all points along the skyline. This line length is found by placing the log, with its minimum required clearance along the terrain as described in the section "Terrain Point Step Size." The line length for each of these points along the terrain is then determined. The line length is then fixed at the shortest of these lengths.

The carriage clearance is found from the equations shown for log drag of a live skyline. Once the carriage clearance ($C_1$) is found, using Figures 1 and 4, the skyline length can be found from the following equations:

First, from the geometry of Figures 1 and 4:

$$Y_8 = Y_9 + C_1 \tag{140}$$

$$Y = Y_1 - Y_8 \tag{141}$$

$$H = Y_2 - Y_1 \tag{142}$$

$$D = X_8 - X_1 \tag{143}$$

Then the skyline length can be found from the following equation:

$$U_5 = \sqrt{D^2+Y^2} + \sqrt{(L-D)^2+(Y-H)^2} \tag{144}$$

This analysis assumes straight line segments and neglects line stretch.

Once the line length is set, the vertical distance from the carriage to the top of the headspar (Y) can be found from the elliptical load path equations developed by Carson (1). These equations were modified to use the variables from the rest of this analysis. These equations are as follows:

$$E = \frac{U_4}{\sqrt{L^2+H^2}} \tag{145}$$

$$M = E^2 + H^2(E^2-1)/L^2 \tag{146}$$

$$N = E(1-2D/L) \tag{147}$$

$$O = (1-2D/L)^2 - H^2(E^2-1)/L^2 \tag{148}$$

$$N = (-N+ABS(H)\sqrt{N^2-4MO/H})/M \tag{149}$$

$$Y = (H(1+EN+L\sqrt{(E^2-1)(1-N^2)})/2 \tag{150}$$

Once the value of Y is found, the carriage clearance can be found from the following equations:

$$Y8 = Y1 - Y \tag{151}$$

$$C_1 = Y_8 - Y_9 \tag{152}$$

Once the value of $C_1$ is known the horizontal and vertical forces at the carriage from the choker can be found by using the analysis shown for log drag for a standing skyline. Then the formula for determining standing skyline loads and line tensions can be used to find the maximum allowable load for each terrain point and the resulting mainline and skyline tensions.

## Carriage Types

For a standing skyline, which is usually skyline limited, a single mainline type carriage is assumed in the computer program. For a running skyline, which is often mainline limited, and where mechanical slackpulling (MSP) and over/under wound type carriages (Rowley-Parker style) are often used, the computer program offers a choice of using a single mainline type carriage, a MSP type carriage or an over/under wound carriage. For a single mainline type carriage, the equations formulated for a running skyline analysis can be used as formulated in the section "Running Skyline Loads and Line Tensions." Figures 7 and 8 show a free body diagram for a MSP and an over/under wound carriage, respectively.

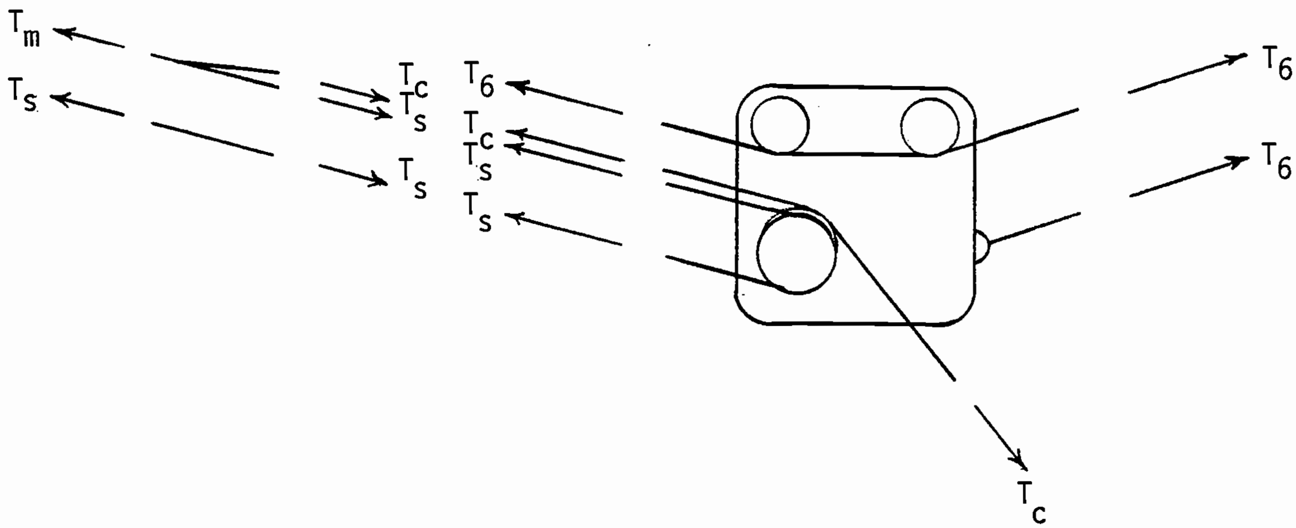



Figure 7. Free Body Diagram for a MSP Type Carriage on a Running Skyline.

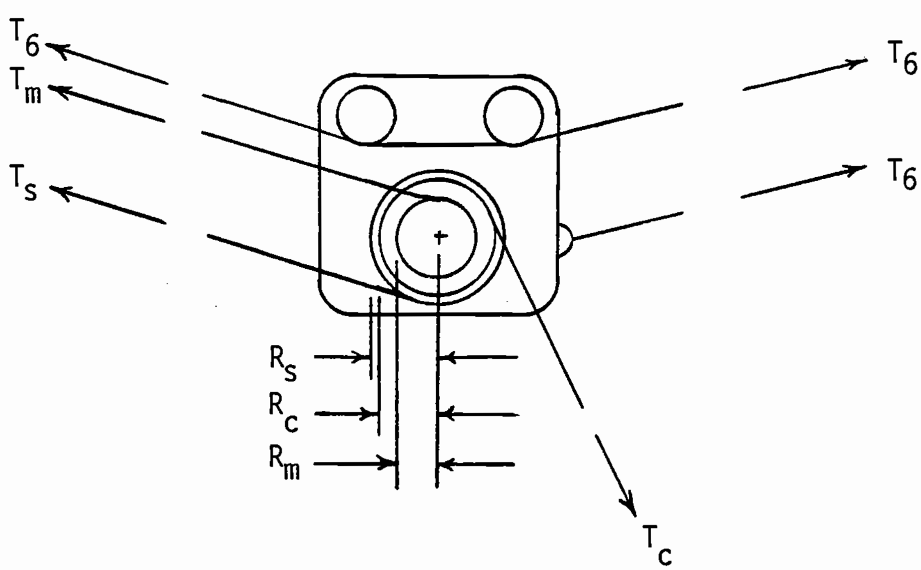



Figure 8. Free Body Diagram for a Over/Under Wound Type Carriage on a Running Skyline.

For a over/under wound carriage as shown above, it is assumed the dropline, mainline and slackpulling line drums in the carriage cannot lock, and therefore, the sum of the moments about the center of the drums must be in balance as shown in the following equation:

$$\Sigma M = 0 \qquad R_m T_m - R_c T_c - R_s T_s = 0 \tag{153}$$

The analysis for a MSP carriage is the same as for a over/under carriage only $R_m = R_c = R_s$.

Let T be the maximum tension the mainline plus the slackpulling line can have at the headspar. If the value of T is known, the equations derived for a running skyline can be used with T in place of the maximum allowable mainline tension and with the mainline plus the slackpulling line weight substituted for the mainline weight. However, the value of T is generally not known and cannot be solved for directly, so an iterative type procedure is needed. The secant method was the iterative procedure chosen for this problem with the value of T as the variable and the difference between the allowable mainline tension and the actual value of the mainline tension for the chosen value of T as the function. The value of T which makes the value of the function equal zero will then be the value of T for which the mainline will be at its maximum allowable tension. For this problem, the value of mainline tension at the headspar can be found as follows:

First, rearranging equation (153) yields:

$$T_m = \frac{Rc}{Rm} T_c + \frac{Rs}{Rm} T_s \tag{154}$$

Let:

$$R_5 = \frac{Rc}{Rm} \tag{155}$$

$$R_6 = \frac{Rs}{Rm} \tag{156}$$

Then substituting equation (155) and (156) into equation (154) yields:

$$T_m = R_5T_c + R_6T_s \tag{157}$$

Solving for $T_s$ yields:

$$T_s = \frac{T_m - R_5T_c}{R_6} \tag{158}$$

The value of T, $T_s$ and $T_m$ can be equated using the following equation:

$$T - WY = T_s + T_m \tag{159}$$

Substituting in equation (159) the value of $T_s$ from equation (158) yields:

$$T - WY = \frac{T_m - R_5T_c}{R_6} + T_m \tag{160}$$

Solving for Tm yields:

$$T_m = (T - WY + \frac{R_5T_c}{R_6}) \frac{R_6}{1+R_6} \tag{161}$$

If the value of the mainline tension at the carriage is known, the tension in the mainline at the headspar can be found as follows:

$$T_{ma} = T_m + W_3Y \tag{162}$$

$$T_{ma} = (T - WY + \frac{R_5 T_c}{R_6}) \frac{R_6}{1+R_6} + W_3 Y \qquad (163)$$

The value of $T_c$ can be found from the following equation:

$$T_c = W_8 \sqrt{C_6^2 + C_7^2}$$

The equation for the function can now be written as follows:

$$F_4 = T_3 - T_{ma} = T_3 - (T - WY + \frac{R_5 W_8 \sqrt{C_6^2 + C_7^2}}{R_6}) \frac{R_6}{1+R_6} - W_3 Y \qquad (164)$$

In the above equation, the value of $W_8$ is found from the equations for determining the maximum allowable load with the mainline being limited. Using the secant method, the equation for choosing a new value of T is the following:

$$T = E_4 - F_4 \frac{E_4 - E_3}{F_4 - F_3} \qquad (165)$$

In this equation $E_4$ is the current value of T, $E_3$ is the last value of T, $F_4$ is the current value of the function, $F_3$ is the last value of the function, and T is the new guess for a value of T.

The iterative procedure is then to choose two initial values for $E_3$ and $E_4$ and find the values of $F_4$ and $F_3$ for these values of T. Then equation (165) is used to determine a new guess of T. The value of $F_4$ is then found for this new value of T using the equations for finding $W_8$ given the value of T and equation (164). This procedure is continued until the value of $F_4$ is within an acceptable tolerance of zero.

Portions of the preceeding analysis and figures used the methods devised by Carson (2, 3), Carson and Mann (4, 5), Peters (9), Sessions (10), and Falk (7).

# SKYLINE ANALYSIS PROGRAM WITH DRAG

A computer program has been written in Basic and placed on the HP 9830 to solve this problem. This computer program is actually two separate computer programs. The first program is for entering and storing the profile data and the yarder specifications. The profile data is stored on the auxiliary cassette and the yarder specifications are stored on the main cassette along with the computer programs. Once the yarder specifications and profile data are stored on the cassette, they do not have to be re-entered and when an analysis is done they can be used over and over.

The second program is for analyzing the profiles determining the allowable loads, mainline tensions, and skyline or haulback tensions. This program uses the yarder specifications and profile data previously stored on the cassettes.

## Profile Input Program

This computer program consists of a mainline memory subprogram, plus ten subprograms on the special function keys 0 through 9. Figure 9 shows the special function key overlay for both programs. The descriptions above the special function keys refer to the profile input program. The descriptions below the special function keys refer to the skyline analysis program.

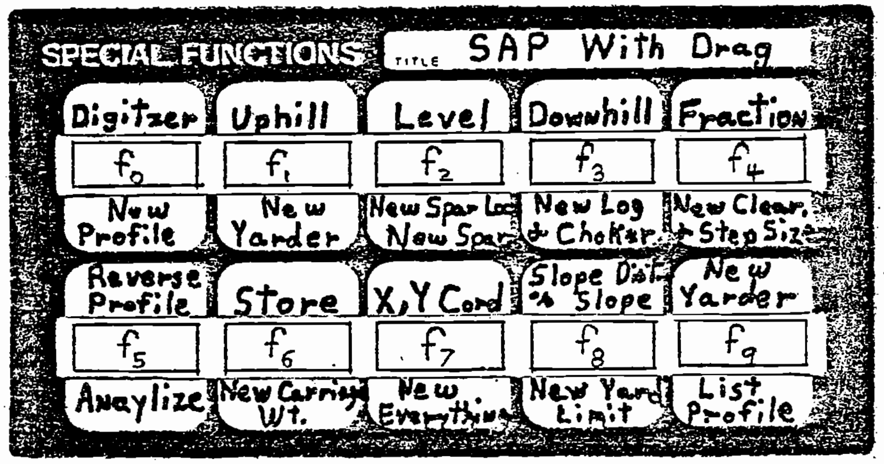
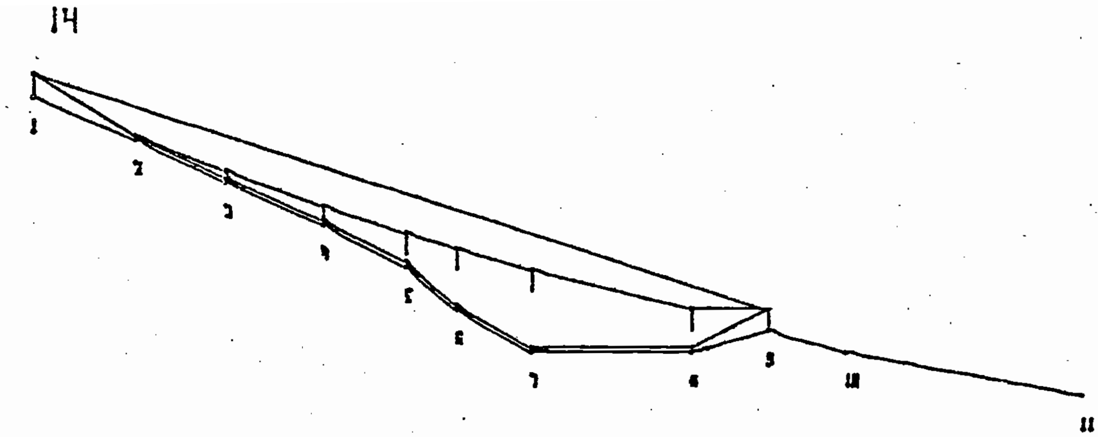



Figure 9. Special Function Key Overlay.

For example, special function key $f_0$ is for entering data from the digitizer in the profile input program and for entering a new profile from tape in the skyline analysis program.

The mainline memory subprogram is for initializing the program and loading the special function key subprograms from tape. Special function keys $f_0$ through $f_4$ are for entering profile data from a contour map using the digitizer. Special function key $f_5$ is for reversing a profile. Special function key $f_6$ is for storing a profile once it is entered. Special function keys $f_7$ and $f_8$ are for entering profile data by X, Y coordinates and slope distance, percent slope data respectively. Special function key $f_9$ is for entering and storing the yarder specifications that are used in the skyline analysis program with drag. The profile inputs and computer programs used for these special function key programs are essentially the same as the ones used on the Skyline Analysis Program (Sessions, 1978).



LIVE AND STANDING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)

YARDER SPECS.-THUNDERBIRD MOBILE YARDER

| | ALLOWABLE LOAD | LINE WEIGHT |
|---|---|---|
| SKYLINE | 34500 | 1.85 |
| MAINLINE | 19600 | 1.04 |
| HAULBACK | 0 | 0.00 |
| SLACKLINE | 0 | 0.00 |

HEADSPAR HT= 45

PROFILE 14

| | | | |
|---|---|---|---|
| CARRIAGE WT= | 600 | TAILSPAR HT= | 40 |
| HEADSPAR T.P.= | 1 | TAILSPAR T.P.= | 9 |
| INN YARD LIM= | 1 | OUT YARD LIM= | 9 |
| LENGTH OF CHOKER= | 8 | LENGTH OF LOG= | 32 |

MIN LOG TO GROUND CLEARANCE= 2
TERRAIN POINT STEP SIZE= 1

LIVE SKYLINE PAYLOADS

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 15141 | 34500 | 10026 | 8.67 | 3.58 |
| 3.0 | 386 | 13383 | 34500 | 8554 | 8.51 | 3.58 |
| 4.0 | 581 | 12609 | 34500 | 8055 | 8.88 | 3.58 |
| 5.0 | 746 | 13284 | 34500 | 8448 | 11.68 | 3.58 |
| 6.0 | 847 | 24973 | 34500 | 14792 | 9.20 | 3.58 |
| 7.0 | 997 | 47373 | 34500 | 18088 | 9.06 | 3.58 |
| 8.0 | 1322 | 51380 | 34500 | 7164 | 9.94 | 3.58 |

STANDING SKYLINE PAYLOADS BASED ON A SKYLINE LENGTH OF 1548.43 FT.

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 14697 | 34500 | 9623 | 8.67 | 5.40 |
| 3.0 | 386 | 7900 | 34500 | 4434 | 21.29 | 26.71 |
| 4.0 | 581 | 4869 | 34500 | 2149 | 35.78 | 57.18 |
| 5.0 | 746 | 4315 | 34500 | 1736 | 64.69 | 51.49 |
| 6.0 | 847 | 4323 | 34500 | 1708 | 115.48 | 62.01 |
| 7.0 | 997 | 4611 | 34500 | 1720 | 154.48 | 90.00 |
| 8.0 | 1322 | 8168 | 34500 | 1862 | 81.67 | 104.57 |

REQUIRED RIGGING LENGTH= 1765.16

Figure 10. Typical Printout.

However, the programs were all slightly modified to simplify the input and storing of the profiles. Appendix 1 contains a users guide for using this program. Appendix 2 contains a copy of the program statements for this program.

Skyline Analysis Program with Log Drag

Figure 10 shows a typical printout of the output for this program. The yarder specifications and profile data are all entered from tape which was stored in the profile input program. The carriage weight, tailspar height, headspar terrain point number, tailspar terrain point number, inner yarding limit, outer yarding limit, length of the choker, length of the log, minimum log to ground clearance, and terrain point step size, were all entered in this program. The terrain point, span, maximum log load, skyline tension, mainline tension, carriage clearance, log to ground angle, and required rigging length are all output by this program.

In this program, the mainline memory subprogram initializes the program and loads the special function key programs from the cassette tape. Referring again to Figure 9, the descriptions below the special function key apply to the skyline analysis program with log drag. Special function key $f_5$ enters the program inputs, analyzes the data, and prints the outputs. Once the first profile has been analyzed, special function keys $f_0$ through $f_4$ and $f_6$ through $f_8$ are used to change the inputs specified by the user which are then analyzed using special function key $f_5$. For example, after the first profile has been run using special function key $f_5$, special function keys $f_0$ and $f_6$ could be used to change the profile data and the carriage weight before analyizing the data using special function key $f_5$ again. The yarder data, log and choker data, log clearance and terrain point step size would all remain the same and would not have to be input again. If all new data is required for the next analysis after the first profile is run, then special function key $f_7$ would be used before using special function key $f_5$ again. Special function key $f_9$ just gives another listing of the profile. The profile is also listed in the profile input program. The computer programs were set up in this way to require the least amount of input.

Appendix 1 contains a users guide for using this program and Appendix 3 contains a copy of the program statements for this program.

# EFFECTS OF THE PARAMETERS USED IN COMPUTING THE ALLOWABLE LOADS AND LINE TENSIONS

Appendix 4 contains sample profiles and computer runs to demonstrate the effects of the various parameters. Figures 17 and 28 in Appendix 4 show the basic profiles and inputs. The parameters were varied from this basic data one at a time, to show the effects of the parameters. The following is a discussion of these computer outputs, and the effects of the various parameters.

## Choker Angle

The smaller the choker angle (A in Figure 1), the higher the horizontal component of the force at the carriage from the choker will be ($H_4$ in Figures 5 and 6) and the lower the vertical component of the force at the carriage from the choker ($V_4$ in Figures 5 and 6). As the horizontal component of the force increases and the vertical component of the force decreases in the choker, this causes an increase in the mainline tension and a decrease in the skyline tensions. If the skyline is limiting the allowable load, then the allowable load would increase as the choker angle decreases. However, if the mainline is limiting the allowable load, then the allowable load would decrease as the choker angle decreases. Most of the parameters discussed in the following sections affect the line tensions in this manner, by changing the choker angle and horizontal and vertical components of the force at the carriage, shifting the effects of load from one line to the other.

## Length of Log

Figures 18 and 19 show the effects of the length of the log. For this example the skyline is limiting, and a longer log causes a higher mainline tension and a higher maximum log load, a longer log causes an increase in the horizontal component of the force at the carriage, a decrease in the vertical component of the force at the carriage, and a smaller choker angle. This causes a transfer of the force from the skyline to the mainline, which allows a higher log load, if the skyline is limiting. If the mainline were limiting, a longer log would decrease the allowable load.

## Log to Ground Clearance

Figures 17, 20 and 21 show the effect of the log to ground clearance (C in Figure 1). Again in this example, the skyline is always limiting and the higher the log to ground clearance, the lower the maximum log load, and the lower the mainline tensions. Higher log to ground clearances cause a higher vertical component of the force at the carriage, and a larger choker angle. This causes a transfer of some of the load from the mainline to the skyline and decreases the allowable load if the skyline is limiting.

## Length of Choker

Figures 17 and 22 show the effects of the length of the choker. A longer choker causes a shortening of skyline in order to maintain the minimum log to ground clearance. In the example this caused a decrease in the maximum log load and a decrease in the mainline tensions. For a given log weight, the horizontal component and vertical component of the force in the choker at the carriage remain the same and the choker angle remains the same. For a given log weight the shorter the skyline, and less the deflection, the higher the tension in the skyline. So if the skyline is limiting, the shorter the choker length the higher the load that can be carried.

## Point of Choker Attachment

In the computer program, the choker is assumed to be attached 2 feet from the end of the log. This value can easily be changed in the computer program or could easily be made an input. To change the point of choker attachment in the computer program, the value of $D_3$ needs to be changed in statement number 30. The point of choker attachment was changed from 2 feet to 14 feet from the end of the log in the computer program and the results of the output are shown in Figure 23. Comparing Figure 17 ($D_3$=2) and Figure 23 ($D_3$=14), placing the choker closer to the center of the log caused a decrease in maximum load and decreased the mainline tension. The negative mainline tension at terrain point 8, indicates the mainline would be slack at this point and the log would slide down the hill without the assistance of the mainline. Placing the choker closer to the center of the log causes the vertical component of the force at the carriage to increase, the horizontal component of the force in the choker at the carriage to decrease, and the choker angle to increase. If the skyline is limiting, then choking the log closer to the center causes a decrease in the maximum log load. If the mainline is limiting then choking the log closer to the center would increase the maximum log load.

## Center of Gravity of the Log

In the computer program, the center of gravity of the log is assumed to be located a distance of half the log length from the end of the log ($C_8$=0.5). This value can be easily changed in the computer program by changing the value of $C_8$ in program line number 85 or this value could easily be made on input. Figures 24 and 25 show an example of the effect of having the center of gravity of the log 0.3 and 0.7 of the length of the log from the end of the log. In this example, having the center of gravity closer to the end of the log ($C_8$=0.3) increased the mainline tension and caused the mainline to be limiting in some cases. Also, the maximum log load increased because the skyline was limiting with $C_8$=0.7. Having the center of gravity closer to the end of the log ($C_8$=0.3) caused more of the load to be taken by the mainline and less to be taken by the skyline. The closer the center of gravity of a log is to the end of the log, the higher the horizontal component of the force in the choker, the lower the vertical component of the force in the choker, and the smaller the choker angle. If the skyline is limiting, a higher load can be carried for a log, with its center of gravity closer to the end of the log. If the mainline is limiting a higher log load can be carried with a log that has its center of gravity farther from the end of the log.

## Coefficient of Friction

Values of the coefficient of friction reported in the literature have generally varied from a value of 0.5 to a value of 1.0 with a value of 0.6

for the coefficient of friction being the most commonly used value in most engineering calculations. The computer program assumes a value of U=0.6, however, this value is very easy to change and could be made an input. Figures 17, 26 and 27 show the effect of the coefficient of friction. The coefficient of friction was 0.6 for output shown in Figure 17, 0.4 for the output shown in Figure 26 and 0.8 for the output shown in Figure 27. For the examples shown in Figures 26 and 27, changing of the coefficient of friction from 0.4 to 0.8 did not significantly change the maximum log loads, but did cause the mainline tensions to increase. For a log with a given one end suspension, increasing the coefficient of friction causes the choker angle to decrease and causes the tension in the choker to increase. When the skyline is limiting, the increase in load from a decreased choker angle is offset by an increase in the choker tension. When the mainline is limiting, increasing the coefficient of friction would cause an increase in the mainline tension and a decreased log load.

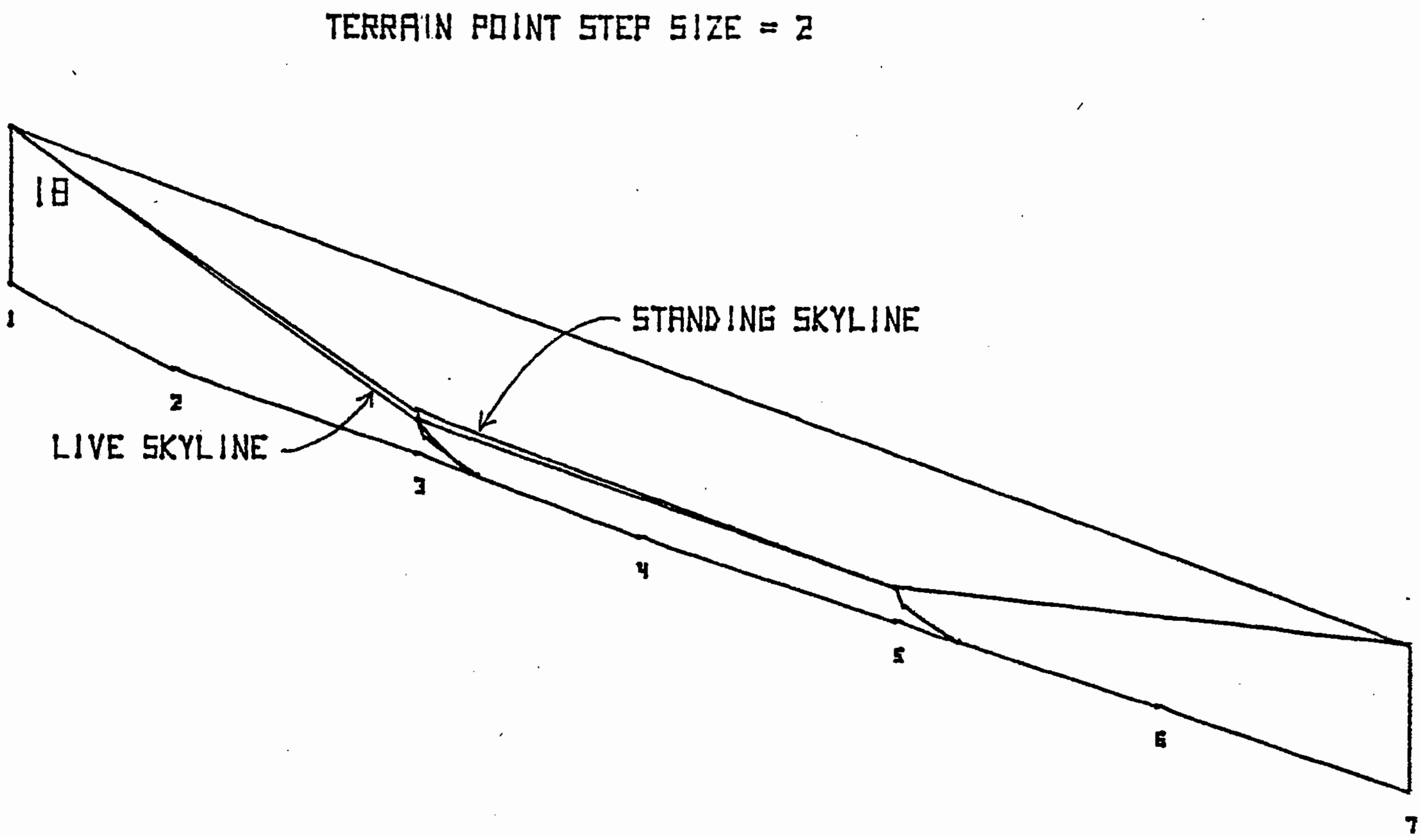
Terrain Point Step Size

Figures 11 and 12 show the effect of the terrain point step size. As shown in Figure 11 for a terrain point step size of 2 every second terrain point is analyzed with the carriage directly above the terrain point and for a terrain point step size of one every terrain point is analyzed. Similarly, for a terrain point step size of 3 every third terrain point would be analyzed and for a terrain point step size of 4 every fourth terrain point would be analyzed. Figure 12 shows that for a terrain point step size of .5 (1/2) two points are analyzed between terrain points, one with the carriage directly above the terrain point and one with the end of the log on the next terrain point. For a terrain point step size of .33 (1/3) three points are analyzed between terrain points as shown in Figure 12. Similarly for a terrain point step size of .25 (1/4) four points between terrain points would be analyzed and for a terrain point step size of .20 (1/5) five points between terrain point would be analyzed. The advantage in analyzing more terrain points is that the critical point for the payload is more likely found. Also, for a standing skyline analyzing more terrain points assures that the minimum line length is more accurately found.

## Type of Carriage for a Running Skyline

Figures 28, 29, 30, and 31 show the effect of the different types of carriages. In these examples the mainline is always limiting. The MSP carriage gave the highest log loads, the over/under wound carriage with $R_5=R_6=1.5$ the second highest loads, the over/under wound carriage with $R_5=R_6=2.0$ the third highest log loads, and the single mainline type carriages giving the lowest loads.* However, the single mainline carriage gave a higher load on a few of the terrain points with flatter or downhill slopes. For the downhill and the flatter uphill slopes, more of the log load is transferred to the haulback with a single mainline carriage, since the choker tension is not transferred directly to the mainline through a sheave or series of drums in the carriage. The MSP and over/under wound carriages are generally more efficient, since the slackpulling line carries a portion of the load. The smaller the ratios of the mainline drum

*See the section on carriage types for an explanation of $R_5$ and $R_6$.



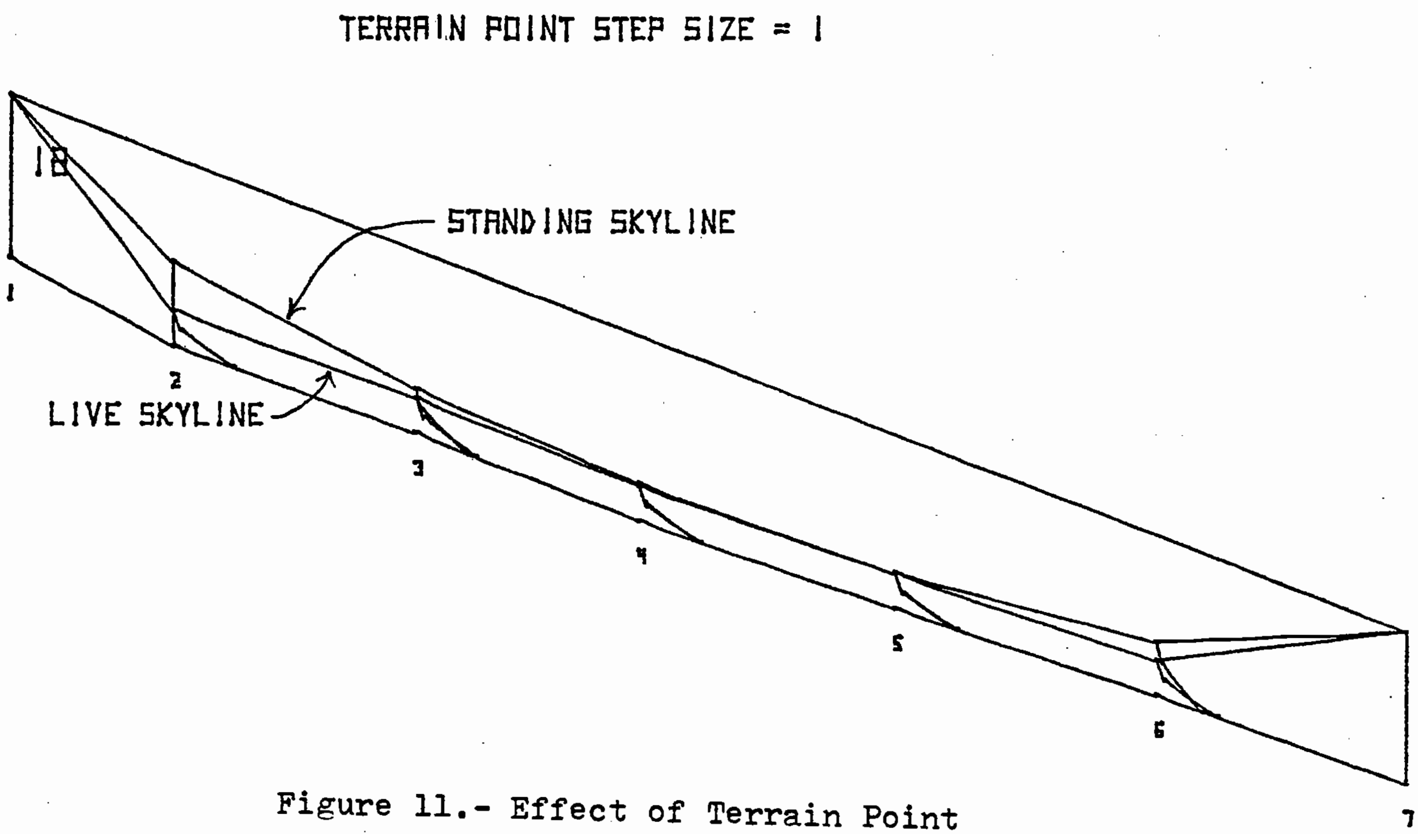
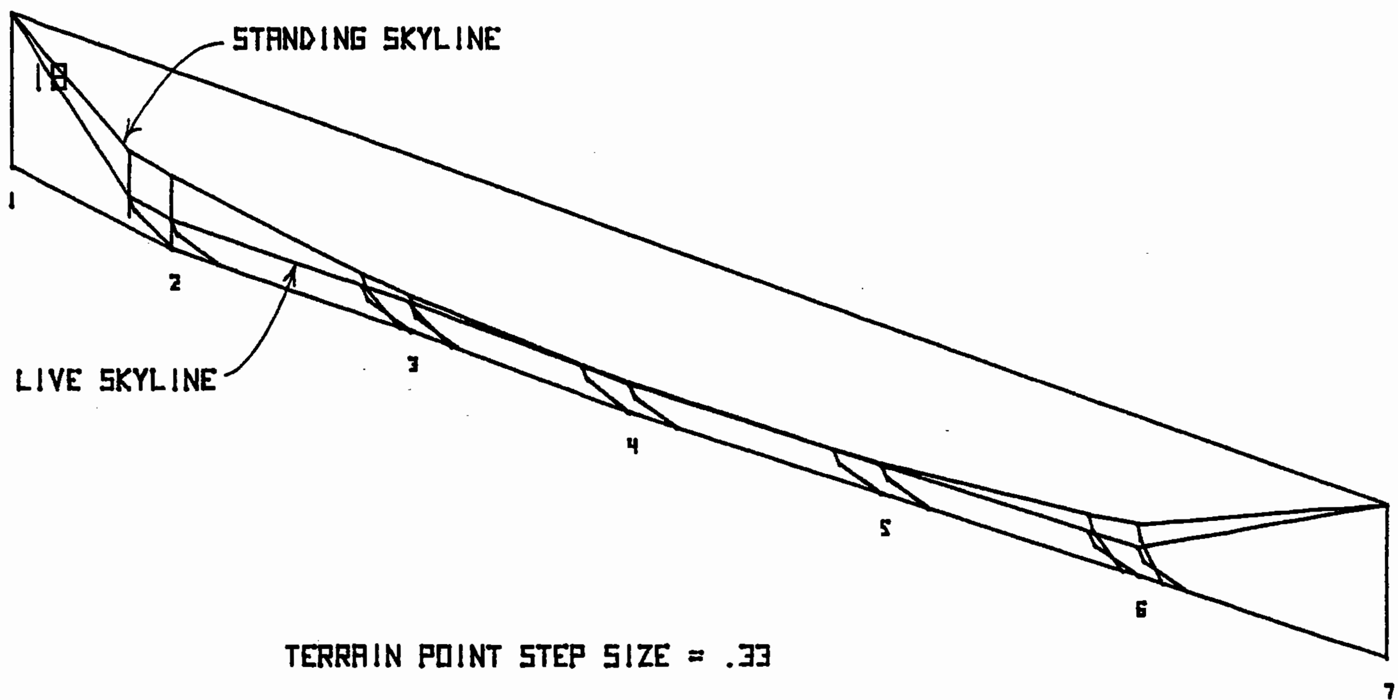




Figure 11.- Effect of Terrain Point
Step Size.

TERRAIN POINT STEP SIZE = .5




TERRAIN POINT STEP SIZE = .33

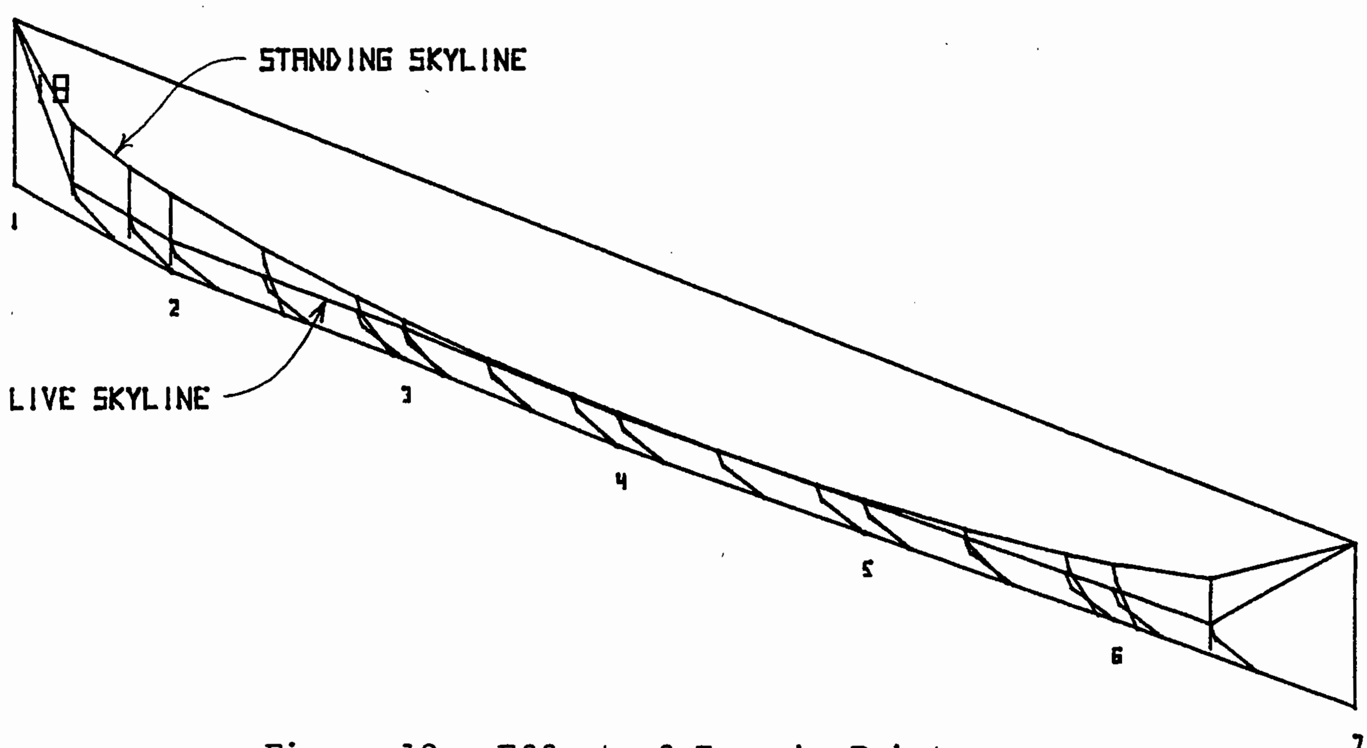


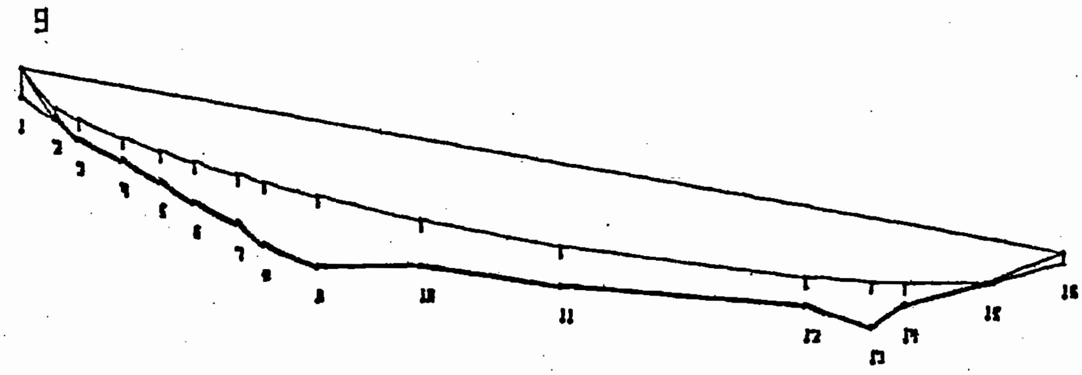

Figure 12.- Effect of Terrain Point Step Size.

diameter to the dropline and slackpulling line drum diameter ($R_5$ and $R_6$), the more efficient is the over/under wound carriage and the more load the slackpulling line will carry.

## COMPARISON WITH SKYLINE ANALYSIS PROGRAM

Figure 13 shows an example of the output from the Skyline Analysis Program on the HP 9830. The value input for the loaded carriage clearance to insure a specified amount of one end suspension is generally a guess. A value of 9 was used in this example because it was the average carriage clearance found using the Skyline Analysis Program with Drag (Figure 14). In the standing skyline output, the carriage clearance can greatly vary and it is generally a guess whether to use the dragging load or the flying load for the actual loads. The value for the dragging loads was determined by multiplying the flying log loads by 1.5. The Skyline Analysis Program does not determine or limit the mainline tensions. To accurately determine the mainline tension for a dragging log, the horizontal component of the force from the choker has to be used in the analysis. Figure 14 shows the output for this same profile using the Skyline Analysis Program with Drag. For the live skyline analysis, which would have a dragging load, the Skyline Analysis Program with Drag gave a lower payload for the first few terrain points since the mainline was limiting and the Skyline Analysis Program on the HP 9830 does not even check the mainline tensions. For the rest of the terrain points, the Skyline Analysis Program with Drag gave higher payloads. The negative mainline tension for terrain point 13 indicates the mainline is slack and the log would be sliding down the hill. For the standing skyline payloads, the two programs give similar results, since the load is flying for most of the terrain points.

This example demonstrates that for a dragging log, using the fully



LIVE SKYLINE LOAD ANALYSIS (RIGID LINK ASSUMPTION)

ALLOWABLE SKYLINE TENSION= 64000

| | | | |
|---|---|---|---|
| SKYLINE WT= | 3.50 | MAINLINE WT= | 2.34 |
| HEADSPAR HT= | 110 | TAILSPAR HT= | 2 |
| HEADSPAR T.P.= | 1 | TAILSPAR T.P.= | 16 |
| INN YARD LIM= | 1 | OUT YARD LIM= | 16 |

CARRIAGE WT= 4000
LOADED CARRIAGE CLEARANCE= 9

| TERRAIN POINT | LOG LOAD (FLY) | LOG LOAD (DRAG) | LINE LENGTH |
|---|---|---|---|
| 2 | 63318 | 94977 | 4273 |
| 3 | 51645 | 77468 | 4291 |
| 4 | 33984 | 50976 | 4290 |
| 5 | 29574 | 44360 | 4300 |
| 6 | 28505 | 42758 | 4315 |
| 7 | 26110 | 39165 | 4325 |
| 8 | 27799 | 41699 | 4349 |
| 9 | 25502 | 38252 | 4357 |
| 10 | 15052 | 22578 | 4307 |
| 11 | 11569 | 17354 | 4295 |
| 12 | 11193 | 16790 | 4280 |
| 13 | 18845 | 28267 | 4315 |
| 14 | 13679 | 20519 | 4273 |
| 15 | 10539 | 15809 | 4237 |

NEW SPAR LOCATION = 0
NEW YARDER SPEC = 1
REQD RIGGING LENGTH = 2
STANDING SKYLINE PLOT= 3

STANDING SKYLINE PAYLOADS (BASED ON MIN LIVE SKYLINE LENGTH)

| STATION | LOG LOAD (FLY) | LOG LOAD (DRAG) | CLEARANCE |
|---|---|---|---|
| 414 | 13594 | 20391 | 129 |
| 828 | 6331 | 9496 | 228 |
| 1242 | 3302 | 4953 | 295 |
| 1656 | 1673 | 2509 | 217 |
| 2071 | 811 | 1217 | 198 |
| 2485 | 567 | 850 | 167 |
| 2899 | 1046 | 1569 | 143 |
| 3313 | 2769 | 4153 | 180 |
| 3727 | 7921 | 11882 | 33 |

Figure 13. Output from the Skyline Analysis Program.

LIVE AND STANDING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)



YARDER SPECS -SKAGIT BU-199

| | ALLOWABLE LOAD | LINE WEIGHT |
|---|---|---|
| SKYLINE | 64000 | 3.50 |
| MAINLINE | 43300 | 2.34 |
| HAULBACK | 0 | 0.00 |
| SLACKLINE | 0 | 0.00 |

HEADSPAR HT= 110

PROFILE 9

| | | | |
|---|---|---|---|
| CARRIAGE WT= | 4000 | TAILSPAR HT= | 2 |
| HEADSPAR T.P.= | 1 | TAILSPAR T.P.= | 16 |
| INN YARD LIM= | 1 | OUT YARD LIM= | 16 |
| LENGTH OF CHOKER= | 8 | LENGTH OF LOG= | 32 |

MIN LOG TO GROUND CLEARANCE= 2
TERRAIN POINT STEP SIZE= 1

LIVE SKYLINE PAYLOADS

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 133 | 47345 | 28663 | 43300 | 12.46 | 3.58 |
| 3.0 | 225 | 53091 | 29553 | 43300 | 8.78 | 3.58 |
| 4.0 | 397 | 57318 | 52690 | 43300 | 9.27 | 3.58 |
| 5.0 | 544 | 58642 | 64000 | 43081 | 9.76 | 3.58 |
| 6.0 | 677 | 61999 | 63846 | 43300 | 8.78 | 3.58 |
| 7.0 | 848 | 43220 | 64000 | 31294 | 11.26 | 3.58 |
| 8.0 | 954 | 62952 | 64000 | 41302 | 8.39 | 3.58 |
| 9.0 | 1166 | 67328 | 64000 | 32241 | 9.06 | 3.58 |
| 10.0 | 1576 | 33663 | 64000 | 18088 | 8.43 | 3.58 |
| 11.0 | 2132 | 25162 | 64000 | 12474 | 8.67 | 3.58 |
| 12.0 | 3110 | 19742 | 64000 | 10204 | 8.26 | 3.58 |
| 13.0 | 3361 | 35391 | 64000 | -6302 | 7.84 | 3.58 |
| 14.0 | 3493 | 29145 | 64000 | 7121 | 9.93 | 3.58 |
| 15.0 | 3823 | 21901 | 64000 | 6575 | 9.93 | 3.58 |

STANDING SKYLINE PAYLOADS BASED ON A SKYLINE LENGTH OF 4236.13 FT

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 133 | 34174 | 64000 | 13016 | 70.17 | 49.11 |
| 3.0 | 225 | 22703 | 64000 | 11767 | 109.88 | 65.01 |
| 4.0 | 397 | 13955 | 64000 | 7067 | 126.96 | 61.54 |
| 5.0 | 544 | 10210 | 64000 | 5358 | 159.64 | 58.91 |
| 6.0 | 677 | 8001 | 64000 | 4475 | 200.55 | 65.01 |
| 7.0 | 848 | 5992 | 64000 | 3795 | 233.56 | 52.85 |
| 8.0 | 954 | 5053 | 64000 | 3539 | 286.26 | 69.29 |
| 9.0 | 1166 | 3604 | 64000 | 3278 | 314.63 | 90.00 |
| 10.0 | 1576 | 1811 | 64000 | 3363 | 224.14 | 81.81 |
| 11.0 | 2132 | 632 | 64000 | 4022 | 198.16 | 85.32 |
| 12.0 | 3110 | 1586 | 64000 | 5451 | 136.65 | 72.33 |
| 13.0 | 3361 | 2981 | 64000 | 5820 | 192.03 | 121.22 |
| 14.0 | 3493 | 4158 | 64000 | 6023 | 101.94 | 103.62 |
| 15.0 | 3823 | 21965 | 64000 | 6580 | 9.93 | 3.14 |

REQUIRED RIGGING LENGTH= 4599.92

Figure 14. Output from the Skyline Analysis Program with Drag.

suspended payload or using the fully suspended payload and the "rule of thumb" that a 1.5 times greater load can be dragged than flown, can result in payloads which differ by over 50 percent.

## ASSUMPTIONS AND LIMITATIONS

1. The log diameter was neglected in the analysis. For a log which is reasonably long as compared to its width, with its choker located near the end, and the center of gravity near the center of the log, the amount of error will be small in neglecting the log diameter. Peters (9) developed equations similar to Carson's (2) which consider the effects of the diameter. These equations could be used, only they are a little more complex and would require an additional input to the program for log diameter.

2. The cable segments were all analyzed using a rigid link analysis as an approximation to the more accurate catenary-type analysis. The error involved in using a rigid link analysis is generally small for taut cables. Since the skyline systems are analyzed using the maximum log weight, the skyline in the standing skyline and live skyline analysis is generally taut. When yarding uphill, a dragging log tends to increase the mainline tensions, so the mainline will usually be reasonably taut for a dragging log. In the running skyline analysis, all of the cables help provide lift, so all of the cables will generally be taut. The biggest possible source of error in the skyline analysis using the rigid link assumption, would be in the mainline for a fully suspended load in the standing skyline analysis or in the slackpulling line in the running skyline analysis. The cables could be analyzed using the catenary relationships or just the mainline and slackpulling line could be analyzed, using the catenary relationships to help

minimize this error. However, the catenary equations require an iterative type solution, which requires more time to compute, especially on the HP 9830, which is slower than some of the newer desk top computers. Also, an error statement could be added to the program to indicate when the rigid link assumption is in error.

3. If a haulback line is used with a standing or live skyline and has tension in it during the inhaul, it could greatly change the payloads. Mechanical slackpulling carriages and over/under wound type carriages are sometimes used in live and standing skylines. The option to use a haulback line, a mechanical slackpulling carriage and over/under wound type carriage could also be added to the program for a standing and live skyline.
4. In some situations, the tension in a line can become negative to obtain static equilibrium. When the log slides down the hill, the mainline tension becomes negative. In these situations where there is a negative tension in the lines, the loads computed will be in error. A haulback line could be added to the analysis when the mainline tension becomes negative.
5. The effects of line stretch are neglected in the analysis. This will cause some error in the standing skyline analysis.
6. The horizontal distance from the carriage to the end of the log must be less than the distance between terrain points, for a terrain point to be analyzed.
7. The maximum allowable tensions are assumed to occur at the headspar. For downhill yarding, whenever the tailspar elevation is higher than the headspar elevation, the skyline and mainline tensions may be

greater at the tailspar and the carriage than the values input for the maximum allowable tensions. For downhill yarding, an analysis procedure which uses a fully suspended load should be used.

# CONCLUSIONS

The method described in this paper provides a means to determine the load carrying capacity of skylines when partial suspension of the logs is used. As shown in the example problems, the load carrying capacity of a skyline system can vary from the result obtained using log drag by over 50% when log drag is neglected. A correction factor of 1.5 has been used in the past to determine the increase in payload for a dragging log. This correction factor only applies to the skyline and does not consider the mainline tensions. Also, this factor varies with the ground slope, length of the log, log to ground clearance, choker length, point of choker attachment, center of gravity of the log and coefficient of friction. If the mainline tensions are to be considered in skyline analysis with a dragging log, a factor has to be used to determine both the decrease in the vertical component of the force and the increase in the horizontal component of the force in the choker at the carriage. The best method of determining these factors is to use a log drag analysis. This paper describes one such method.

Often when determining the load carrying capacity of a skyline system, several of the parameters such as length of log, length of choker, point of choker attachment, center of gravity of the log, and coefficient of friction are unknown. However, realistic estimates can usually be determined and the effect of different values for these parameters can be determined to arrive at a realistic load carrying capacity for a given skyline operating over a particular terrain.

The computer program presented is as easy to use as the Skyline Analysis Program, which does not consider log drag. If this type of analysis is considered to be too sophisticated, or it is felt that realistic estimates of the parameters cannot be found, then this type of analysis can be used as a comparison to demonstrate the difference in payloads which can occur from using a flying payload and a correction factor of 1.5, or a flying payload for a dragging log.

# A P P E N D I X

# I

# SKYLINE ANALYSIS PROGRAM WITH LOG DRAG USERS GUIDE*

This program inputs profile data, inputs cable system geometry, determines skyline payloads, mainline tensions, and skyline tensions including the effects of a dragging log and the log and ground geometry.

## ASSUMPTIONS AND LIMITATIONS

1. The effects of line stretch are neglected.
2. The maximum allowable tensions are assumed to occur at the headspar. For downhill yarding, the skyline and mainline tensions may be greater at the tailspar and the carriage than the values input for the maximum allowable tensions.
3. The horizontal distance from the carriage to the end of the log must be less than the distance between terrain points, for a terrain point to be analyzed.
4. The program assumes the choker is attached 2 feet from the end of the log and the center of gravity of the log is located in the center of of the log.
5. The loaded cables are assumed to be rigid links. This error is generally small for taut cables. If low tensions occur an error check such as Carson's (1) HP 67 error in rigid link program should be used.

*Portions of the users guide were copied from the Skyline Analysis Program (SAP) documentation (Sessions, 1978).

6. The minimum log to ground distance used in the program is the distance perpendicular to the ground to the top of the front end of the log.
7. The choker length used in the program is the distance from the carriage to the top of the log.
8. When a negative tension occurs the payload is in error.

GENERAL OPERATING NOTES

1. All data is input in response to visual prompters. If more than one piece of data is requested, the pieces of data must be separated by a comma.
2. All data is entered into the program by pressing EXECUTE. Always check the display before pressing EXECUTE; because what you see is what you get.
3. All spar locations are referenced by Terrain Point Numbers and fractions are acceptable.
4. Loads are calculated only at those points the user defines when responding to the prompter "TERRAIN POINT STEP SIZE." For example, if the user inputs "1", the payload is calculated at each terrain point between supports. For "2", every other point is calculated, for "3", every third point, and so forth.
5. Terrain data from the digitizer is entered using the method developed by Carson in PNW-31. Special Function Keys 0-4 correspond to those functions in PNW-31. Several applicable pages from PNW-31 are attached.
6. When analysis of any profile has been completed, a new profile can be generated by pressing a Special Function Key.

7. If the user makes an input error at any time, the system will recover if the Special Function Key corresponding to the particular operation is repressed and the data re-entered as requested by the display.
8. The analysis program assumes the yarder is on the left.
9. Visual prompters requiring a "yes" or "no" answer require use of "1" or "0".

The Skyline Analysis Program with Drag actually consists of two separate computer programs.

The first program enters and stores profile data and yarder specifications. The profile data is stored on the auxiliary cassette, and the yarder specifications are stored on the main cassette along with the computer programs. Once the yarder specifications and profile data are stored on the cassettes they can be entered from the cassettes, and the data does not have to be re-entered when used more than once.

The second program is for analyzing the profiles, determining the allowable loads, mainline tensions, and the skyline or haulback tensions. This program uses the yarder specifications and profile data previously stored on the cassettes.

Figure A shows a copy of the special function key overlay for both of the programs. The descriptions above the special function keys refer to the profile input program. The descriptions below the special function keys refer to the skyline analysis program. For example, special function key $f_0$ is for entering data from the digitizer in the profile input program and for entering a new profile from cassette tape in the Skyline Analysis Program with Drag.

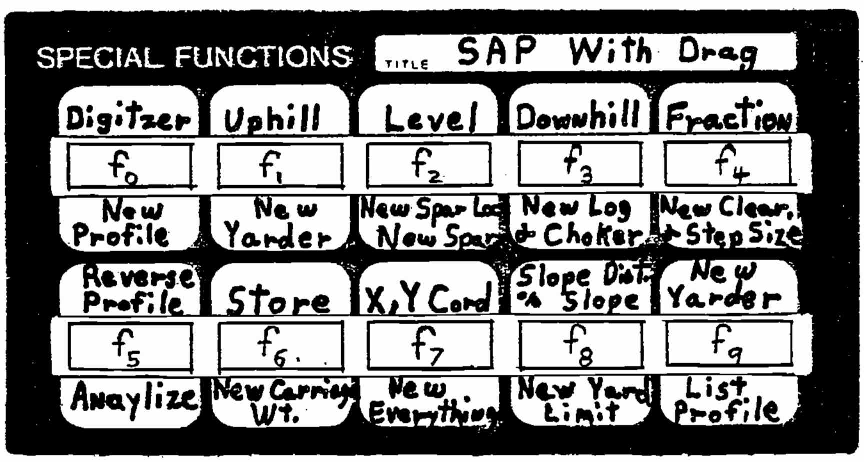



Figure A.- Special Function Key Overlay.

In the profile input program, special function keys $f_0$ through $f_4$ are for entering profile data from a contour map using the digitizer. Special function key $f_5$ is for reversing a profile. Special function key $f_6$ is for storing a profile once it has been entered. Special function keys $f_7$ and $f_8$ are for entering profile data by X, Y coordinates and slope distance, percent slope data respectively. Special function key $f_9$ is for entering and storing yarder specifications. These profile inputs and computer programs are essentially the same as the ones used in the Skyline Analysis Program (Sessions, 1978). However, the programs were all slightly modified to simplify the input and storing of the profiles.

In the Skyline Analysis Program with Drag special function key $f_5$ enters the program inputs, analyzes the data, and prints the outputs. Once the first profile has been analyzed, special function keys $f_0$ through $f_4$ and $f_6$ through $f_8$ are used to change the inputs specified by the user. Once the inputs have been changed, special function key $f_5$ is used to analyze the data. For example, after the first profile has been run using special function key $f_5$, special function keys $f_0$ and $f_5$ could be used to change the profile data and the carriage weight before analyzing the data using special function key $f_5$ again. The yarder data, log and choker data, tailspar height, log clearance and terrain point step size would all remain the same and would not have to be input again. If all new data is required for the next analysis after the first profile is run, then special function key $f_7$ would be used before using special function key $f_5$ again. Special function key $f_9$ gives a listing of the profile data.

The following example problem demonstrates the use of this program. When entering a different profile the same general procedure should be followed.

Example

User Instructions

The following example demonstrates the use of the program.

1. Place plotter paper on the plotter, switch it "on" and engage the "chart hold" key.
2. Set the plotting limits.
3. Place the program cassette into the cassette transport on the calculator. Be absolutely certain that the front of the cassette, which is labelled, faces outward.
4. Place the data tape into the peripheral unit, switch that unit "on".
5. Press the REWIND button for that unit.
6. If terrain data is to be entered from a map, then switch on the digitizer and tape map on digitizer surface.
7. Switch the calculator and the printer "on". Press the REWIND key on the calculator.
8. Press the SCRATCH A and EXECUTE keys.
9. Press LOAD and EXECUTE keys.
10. Press RUN and EXECUTE keys.
11. All user inputs are entered by typing the input on the keyboard and pressing the EXECUTE key.
12. Continue with the procedure outlined in the following table by responding to the visual prompters with the numerical entries indicated in the middle column. The descriptions should be read for an understanding of the process.

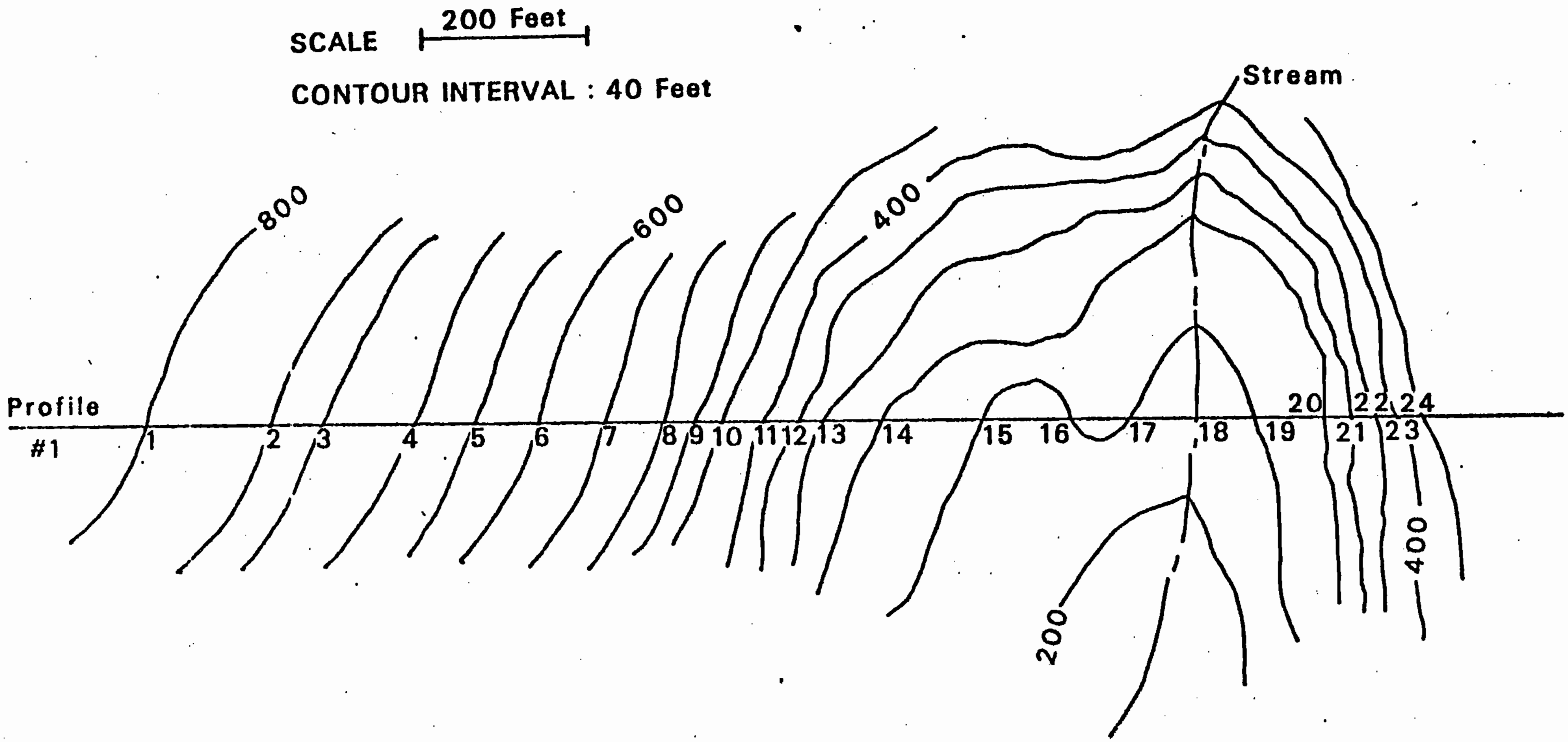



Figure B.—Contour map.

Input Explanation for the Example Problem

| VISUAL PROMPTER ON DISPLAY | KEYBOARD RESPONSE | DESCRIPTION |
|---|---|---|
| GO TO SPECIAL FUNCTION KEYS | $f_0$ | Selects digitizer input of the profile. |
| MAP SCALE (FT/INCH)? | 200 | Enters scale of the map being used. |
| CONTOUR INTERVAL (FT)? | 40 | Enters contour interval of the map being used. |
| HORIZONTAL GRAPH LIMITS (FT)? | 2000 | Enters scale value for X-axis on plotter. |
| PROFILE NUMBER? | 1 | Enters number of profile to be plotted. The profile number must be between 1 and 100. |
| DIGITIZE FIRST POINT AFTER BEEP. | | (DIGITIZER RESPONSE): Set origin and digitize first point on the profile. |
| SELECT A SLOPE AND PROCEED. | | |
| | $f_3$ | Executes program on function key $f_3$ which anticipates downhill profile. |
| | | (DIGITIZER RESPONSE): Digitize all downhill points (2 through 15). |
| | STOP | |
| | $f_2$ | Executes program on function key $f_2$ which anticipates level profile. |
| | | (DIGITIZER RESPONSE): Digitize level section (points 16 and 17). |
| | STOP | |
| | $f_4$ | Executes program on function key $f_4$ which anticipates fractional contour interval. |

| VISUAL PROMPTER ON DISPLAY | KEYBOARD RESPONSE | DESCRIPTION |
|---|---|---|
| FRACTION (+FOR UPHILL; -FOR DOWN)? | +.5 | (DIGITIZER RESPONSE): Digitize next contour (point 19). |
| | STOP | |
| | $f_1$ | Executes program on function key $f_1$ which anticipates uphill profile. |
| | | (DIGITIZER RESPONSE): Digitize remaining uphill points (points 20 and 24). |
| | STOP | |
| | $f_6$ | Stores the profile in the auxiliary cassette. The profile is stored in the file corresponding to the profile number. |
| | $f_9$ | Executes program to enter and store the yarder specifications. |
| YARDER NAME? | SKAGIT BU-739 | Enter the yarder name. |
| ALLOWABLE SKYLINE TENSION (LBS)? | 53300 | Enters the allowable skyline tension. |
| ALLOWABLE MAINLINE TENSION (LBS)? | 34500 | Enters the allowable mainline tension. |
| ALLOWABLE HAULBACK TENSION (LBS)? | 0 | Enters the allowable haulback tension. |
| ALLOWABLE SLACKLINE TENSION (LBS)? | 0 | Enters the allowable slackline tension. |
| SKYLINE WT (LBS/FT)? | 2.89 | Enters the skyline weight per foot. |
| MAINLINE WT (LBS/FT)? | 1.85 | Enters the mainline weight per foot. |
| HAULBACK WT (LBS/FT)? | 0 | Enters the haulback weight per foot. |
| SLACKLINE WT (LBS/FT)? | 0 | Enters the slackline weight per foot. |
| HEADSPAR HT (FT)? | 100 | Enters the headspar height. |
| STORE YARDER IN FILE #(4-20)? | 4 | Stores the yarder specifications in file 4. |

| VISUAL PROMPTER ON DISPLAY | KEYBOARD RESPONSE | DESCRIPTION |
|---|---|---|

Special function keys $f_0$ through $f_9$ should be used until all of the profiles and yarder specifications that are to be analyzed are entered. The next few steps enter the Skyline Analysis Program with Drag which analyzes the profiles and yarder specifications stored on the cassette tapes.

| | | |
|---|---|---|
| | SCRATCH A | Erases all program lines and data from the calculator memory. |
| | LOAD 2 | Loads program from tape. |
| | RUN | Initializes the program. |
| GO TO SPECIAL FUNCTION KEY $f_5$ | $f_5$ | Executes the program to analyze the data. |
| LIVE-1, STAND-2, BOTH-3, RUN-4 SKY? | 2 | Selects type of skyline (3 selects both a live and standing skyline for analysis). |
| LOAD YARDER DATA FROM FILE #? | 4 | Loads yarder data from file 4. |
| PROFILE NUMBER? | 1 | Loads the profile data from file 1. |
| WANT PROFILE PLOTTED? | 1 | Executes plotting of profile. |
| CARRIAGE WT (LB)? | 1000 | Enters the carriage weight. |
| TAILSPAR HT? | 50 | Enters the tailspar ht. |
| HEADSPAR T.P. #, TAILSPAR T.P. # | 1, 24 | Enters the terrain point numbers for the location of the headspar and tailspar. |
| WANT DATA PLOTTED? | 1 | Executes plotting of the data. |
| INNER YARD LIM, OUTER YARD LIM? | 1, 24 | Enters the yarding limits between which the payloads are calculated. |
| LENGTH OF CHOKER (FT)? | 12 | Enters the length of the choker from the carriage to the top of the log. |
| LENGTH OF LOG (FT)? | 32 | Enters the length of the log. |

| VISUAL PROMPTER ON DISPLAY | KEYBOARD RESPONSE | DESCRIPTION |
|---|---|---|
| MIN LOG TO GROUND CLEARANCE? | 5 | Enters the minimum clearance between the top of the front end of the log and the ground. |
| TERRAIN POINT STEP SIZE? | 1 | Enters the terrain point step size. |

The program then analyzes and prints out the data. If only a portion of the data is to be changed for the next analysis, special function keys $f_0$ through $f_4$, $f_6$ and $f_7$ can be used to change the desired information. For example, if we wanted to change the tailspar height and the carriage weight, the following steps would be used.

| | | |
|---|---|---|
| | $f_2$ | Selects changing of the tailspar. |
| TAILSPAR HT? | 30 | Enters new tailspar height. |
| HEADSPAR T.P. #, TAILSPAR T.P.# | 1, 24 | Enters new spar locations. |
| | $f_6$ | Selects changing of carriage weight. |
| CARRIAGE WT? | 600 | Enters new carriage weight. |
| | $f_5$ | Executes analysis of the data. |
| LIVE-1, STANDING-2, BOTH-3, RUN-4 SKY? | 2 | Enters type of skyline. |
| WANT PROFILE PLOTTED? | 1 | Executes plotting of profile. |
| WANT DATA PLOTTED? | 1 | Executes plotting of data. |

Figures C, D, E, and F show the outputs for this example problem.

```
             *************PROFILE INPUT PROGRAM*************

MAP SCALE =  200   FEET PER INCH
CONTOUR INTERVAL =  40    FEET

PROFILE NUMBER    1
 POINT             SPAN       ELEV DIFF FROM PT1

 1                  0               0
                                          DOWNHILL SLOPE
 2                 158             -40
 3                 224             -80
 4                 340             -120
 5                 416             -160
 6                 496             -200
 7                 578             -240
 8                 654             -280
 9                 692             -320
 10                726             -360
 11                776             -400
 12                824             -440
 13                856             -480
 14                928             -520
 15                1055            -560
                                          LEVEL SLOPE
 16                1167            -560
 17                1241            -560
                                          FRACTIONAL INCREMENT=-20
 18                1325            -580
                                          FRACTIONAL INCREMENT= 20
 19                1397            -560
                                          UPHILL SLOPE
 20                1485            -520
 21                1517            -480
 22                1549            -440
 23                1575            -400
 24                1607            -360

SKAGIT BU-739

                ALLOWABLE     LINE
                   LOAD      WEIGHT
SKYLINE           53300       2.89
MAINLINE          34500       1.85
HAULBACK              0       0.00
SLACKLINE             0       0.00

HEADSPAR HT= 100
```

Figure C.- Output for the example problem.

*****SKYLINE ANALYSIS PROGRAM WITH LOG DRAG*****

STANDING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)

YARDER SPECS. -SKAGIT BU-739

| | ALLOWABLE LOAD | LINE WEIGHT |
|---|---|---|
| SKYLINE | 53300 | 2.89 |
| MAINLINE | 34500 | 1.85 |
| HAULBACK | 0 | 0.00 |
| SLACKLINE | 0 | 0.00 |

HEADSPAR HT= 100

PROFILE 1

| | | | |
|---|---|---|---|
| CARRIAGE WT= | 1000 | TAILSPAR HT= | 50 |
| HEADSPAR T.P.= | 1 | TAILSPAR T.P.= | 24 |
| INN YARD LIM= | 1 | OUT YARD LIM= | 24 |
| LENGTH OF CHOKER= | 12 | LENGTH OF LOG= | 32 |

MIN LOG TO GROUND CLEARANCE= 5
TERRAIN POINT STEP SIZE= 1

STANDING SKYLINE PAYLOADS BASED ON A SKYLINE LENGTH OF 1677.33 FT

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 158 | 45277 | 53300 | 30543 | 16.20 | 12.39 |
| 3.0 | 224 | 32907 | 53300 | 18266 | 27.58 | 32.59 |
| 4.0 | 340 | 24981 | 53300 | 14210 | 23.02 | 23.16 |
| 5.0 | 416 | 17990 | 53300 | 8063 | 36.58 | 48.99 |
| 6.0 | 496 | 14612 | 53300 | 5279 | 50.58 | 64.00 |
| 7.0 | 578 | 13760 | 53300 | 4777 | 65.59 | 62.27 |
| 8.0 | 654 | 13216 | 53300 | 4424 | 83.75 | 43.57 |
| 9.0 | 692 | 13017 | 53300 | 4278 | 113.28 | 40.36 |
| 10.0 | 726 | 12876 | 53300 | 4161 | 144.18 | 51.34 |
| 11.0 | 776 | 12728 | 53300 | 4009 | 171.21 | 50.19 |
| 12.0 | 824 | 12649 | 53300 | 3881 | 199.23 | 38.88 |
| 13.0 | 856 | 12631 | 53300 | 3803 | 231.44 | 60.95 |
| 14.0 | 928 | 12693 | 53300 | 3649 | 254.78 | 72.39 |
| 15.0 | 1055 | 13174 | 53300 | 3420 | 268.23 | 90.00 |
| 16.0 | 1167 | 14121 | 53300 | 3220 | 247.70 | 90.00 |
| 17.0 | 1241 | 15145 | 53300 | 3057 | 236.01 | 76.61 |
| 18.0 | 1325 | 16929 | 53300 | 2789 | 244.96 | 105.52 |
| 19.0 | 1397 | 19368 | 53300 | 2426 | 217.95 | 114.44 |
| 20.0 | 1485 | 24858 | 53300 | -2455 | 174.04 | 141.34 |
| 21.0 | 1517 | 28367 | 53300 | -3700 | 134.66 | 141.34 |
| 22.0 | 1549 | 33684 | 53300 | -6878 | 97.15 | 146.98 |
| 23.0 | 1575 | 40483 | 53300 | -13496 | 61.53 | 141.29 |

REQUIRED RIGGING LENGTH= 2160.85

Figure D.- Output for the example problem.

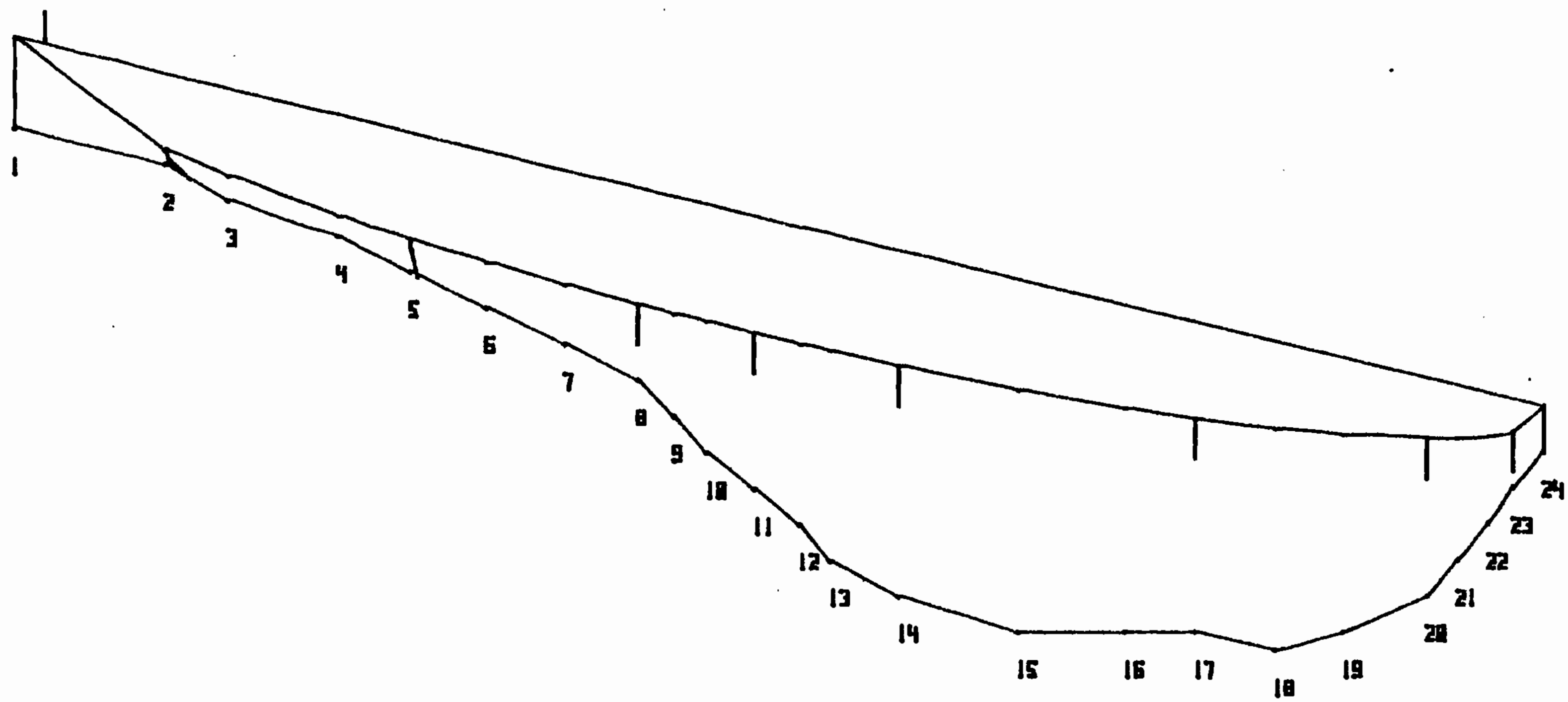



Figure E.- Output for the example problem.

STANDING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)

YARDER SPECS. -SKAGIT BU-739

| | ALLOWABLE LOAD | LINE WEIGHT |
|---|---|---|
| SKYLINE | 53300 | 2.89 |
| MAINLINE | 34500 | 1.85 |
| HAULBACK | 0 | 0.00 |
| SLACKLINE | 0 | 0.00 |

HEADSPAR HT= 100

PROFILE 1

| | | | |
|---|---|---|---|
| CARRIAGE WT= | 600 | TAILSPAR HT= | 30 |
| HEADSPAR T.P. = | 1 | TAILSPAR T.P. = | 24 |
| INN YARD LIM= | 1 | OUT YARD LIM= | 24 |
| LENGTH OF CHOKER= | 12 | LENGTH OF LOG= | 32 |

MIN LOG TO GROUND CLEARANCE= 5

TERRAIN POINT STEP SIZE= 1

STANDING SKYLINE PAYLOADS BASED ON A SKYLINE LENGTH OF 1681.34 FT

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 158 | 44573 | 53300 | 30048 | 16.20 | 12.39 |
| 3.0 | 224 | 32904 | 53300 | 18358 | 27.02 | 31.50 |
| 4.0 | 340 | 25501 | 53300 | 14809 | 21.35 | 20.48 |
| 5.0 | 416 | 18703 | 53300 | 8838 | 34.13 | 43.63 |
| 6.0 | 496 | 14521 | 53300 | 5277 | 47.26 | 64.00 |
| 7.0 | 578 | 13690 | 53300 | 4792 | 61.35 | 62.27 |
| 8.0 | 654 | 13159 | 53300 | 4454 | 78.62 | 43.57 |
| 9.0 | 692 | 12965 | 53300 | 4315 | 107.70 | 40.36 |
| 10.0 | 726 | 12827 | 53300 | 4204 | 138.19 | 51.34 |
| 11.0 | 776 | 12682 | 53300 | 4060 | 164.61 | 50.19 |
| 12.0 | 824 | 12606 | 53300 | 3941 | 192.03 | 38.88 |
| 13.0 | 856 | 12588 | 53300 | 3869 | 223.83 | 60.95 |
| 14.0 | 928 | 12648 | 53300 | 3729 | 246.25 | 72.39 |
| 15.0 | 1055 | 13118 | 53300 | 3528 | 258.02 | 90.00 |
| 16.0 | 1167 | 14045 | 53300 | 3360 | 235.93 | 90.00 |
| 17.0 | 1241 | 15049 | 53300 | 3224 | 223.17 | 76.61 |
| 18.0 | 1325 | 16803 | 53300 | 2992 | 230.85 | 105.52 |
| 19.0 | 1397 | 19205 | 53300 | 2647 | 202.70 | 114.44 |
| 20.0 | 1485 | 24643 | 53300 | 2284 | 157.32 | 141.34 |
| 21.0 | 1517 | 28143 | 53300 | -3211 | 117.36 | 141.34 |
| 22.0 | 1549 | 33495 | 53300 | -6108 | 79.25 | 146.98 |
| 23.0 | 1575 | 40446 | 53300 | -12449 | 43.11 | 141.29 |

REQUIRED RIGGING LENGTH= 2120.85

Figure F.- Output for the example Problem.

# A P P E N D I X

2

# PROFILE INPUT PROGRAM

There is one main program and ten subprograms in the profile input program. The following is a listing of these programs:

## MAIN PROGRAM

```
10 COM Y$[50],T0,T1,T2,T3,W0,W1,W2,W3,H6
20 DIM G5[50],Q5[50],U5[50],V5[50],Z5[50,2]
30 PRINT
40 PRINT TAB15"*************PROFILE INPUT PROGRAM*************"
50 PRINT
60 LOAD  KEY 1
70 D1=0
80 DISP "GO TO SPECIAL FUNCTION KEYS";
90 STOP
100 END
```

# PROGRAM ON $f_0$ KEY

```
XED 0
 D1=0 THEN 60
SP "NEW MAP SPECS.";
IPUT D1
 D1=0 THEN 100
SP "MAP SCALE (FT/INCH)";
IPUT H
ISP "CONTOUR INTERVAL (FT)";
IPUT C
PRINT
PRINT "MAP SCALE = "H" FEET PER INCH"
PRINT "CONTOUR INTERVAL = "C" FEET"
PRINT
D1=1
DISP "PROFILE NUMBER(0-99)";
INPUT N5
DISP "HORZ GRAPH LIMIT(FT)";
INPUT X0
SCALE 0,1.2*X0,0,1.2*X0
PEN
OFFSET 0.1*X0,0.65*X0
PLOT 0,0,-2
PLOT 0,0,1
LABEL (*,2,1.7,0,7/11)
CPLOT 0,2
LABEL (*,2,1.7,0,7/11)N5
PLOT 0,0,1
LABEL (*,1,1.7,0,7/11)
CPLOT 0,-2
LABEL (*,1,1.7,0,7/11)"1"
CPLOT 0,3
S1=E0=E1=N1=0
WRITE (15,350)"PROFILE NUMBER"N5
PRINT
FORMAT F5.0,/," POINT            SPAN        ELEV DIFF FROM PT1"
DISP "DIGITIZE FIRST POINT AFTER BEEP"
WAIT 3000
WRITE (9,*)
ENTER (9,*)X1,Y1
N1=N1+1
PRINT N1,0,0
U[N1]=0
V[N1]=5000
DISP "SELECT A SLOPE AND PROCEED";
STOP
END
```

## PROGRAM ON $f_1$ KEY

```
10 A1=1
20 PRINT TAB40"UPHILL SLOPE"
30 WRITE (9,*)
40 ENTER (9,*)X2,Y2
50 N1=N1+1
60 X=X2-X1
70 Y=Y2-Y1
80 S=SQR(X*X+Y*Y)*H
90 S1=S1+S
100 E1=E1+A1*C
110 E=E1-E0
120 U[N1]=S1
130 V[N1]=V[1]+E
140 PRINT N1,S1,E
150 PLOT S1,E,2
160 LABEL (*,1,1.7,0,7/11)
170 CPLOT -1,-2
180 LABEL (*,1,1.7,0,7/11)N1
190 CPLOT 1,3
200 X1=X2
210 Y1=Y2
220 GOTO 30
230 END
```

## PROGRAM ON $f_2$ KEY

```
10 A1=0
20 PRINT TAB40"LEVEL SLOPE"
30 WRITE (9,*)
40 ENTER (9,*)X2,Y2
50 N1=N1+1
60 X=X2-X1
70 Y=Y2-Y1
80 S=SQR(X*X+Y*Y)*H
90 S1=S1+S
100 E1=E1+A1*C
110 E=E1-E0
120 U[N1]=S1
130 V[N1]=V[1]+E
140 PRINT N1,S1,E
150 PLOT S1,E,2
160 LABEL (*,1,1.7,0,7/11)
170 CPLOT -1,-2
180 LABEL (*,1,1.7,0,7/11)N1
190 CPLOT 1,3
200 X1=X2
210 Y1=Y2
220 GOTO 30
230 END
```

## PROGRAM ON $f_3$ KEY

```
10 A1=-1
20 PRINT TAB40"DOWNHILL SLOPE"
30 WRITE (9,*)
40 ENTER (9,*)X2,Y2
50 N1=N1+1
60 X=X2-X1
70 Y=Y2-Y1
80 S=SQR(X*X+Y*Y)*H
90 S1=S1+S
100 E1=E1+A1*C
110 E=E1-E0
120 U[N1]=S1
130 V[N1]=V[1]+E
140 PRINT N1,S1,E
150 PLOT S1,E,2
160 LABEL (*,1,1.7,0,7/11)
170 CPLOT -1,-2
180 LABEL (*,1,1.7,0,7/11)N1
190 CPLOT 1,3
200 X1=X2
210 Y1=Y2
220 GOTO 30
230 END
```

## PROGRAM ON $f_4$ KEY

```
10 DISP "FRACTION(+FOR UPHILL,-FOR DOWN)";
20 INPUT A1
30 B1=A1*C
40 PRINT TAB40"FRACTIONAL INCREMENT="B1
50 WRITE (9,*)
60 ENTER (9,*)X2,Y2
70 N1=N1+1
80 X=X2-X1
90 Y=Y2-Y1
100 S=SQR(X*X+Y*Y)*H
110 S1=S1+S
120 E1=E1+A1*C
130 E=E1-E0
140 U[N1]=S1
150 V[N1]=V[1]+E
160 PRINT N1,S1,E
170 PLOT S1,E,2
180 LABEL (*,1,1.7,0,7/11)
190 CPLOT -1,-2
200 LABEL (*,1,1.7,0,7/11)N1
210 CPLOT 1,3
220 X1=X2
230 Y1=Y2
240 GOTO 50
250 END
```

## PROGRAM ON $f_5$ KEY

```
10 FIXED 0
20 FOR I=1 TO N1
30 G[I]=U[I]
40 Q[I]=V[I]
50 NEXT I
60 U[1]=0
70 V[1]=V[N1]
80 FOR I=2 TO N1
90 U1=G[N1+2-I]-G[N1+1-I]
100 V1=Q[N1+2-I]-Q[N1+1-I]
110 U[I]=U[I-1]+U1
120 V[I]=V[I-1]-V1
130 NEXT I
140 DISP "PROFILE NUMBER(0-99)";
150 INPUT N5
160 FOR I=(N1+1) TO 50
170 U[I]=0
180 V[I]=0
190 NEXT I
200 FOR I=1 TO 50
210 Z[I,1]=U[I]
220 Z[I,2]=V[I]
230 NEXT I
240 STORE  DATA #5,N5,Z
250 END
```

## PROGRAM ON $f_6$ KEY

```
10 FOR I=(N1+1) TO 50
20 U[I]=0
30 V[I]=0
40 NEXT I
50 FOR I=1 TO 50
60 Z[I,1]=U[I]
70 Z[I,2]=V[I]
80 NEXT I
90 STORE  DATA #5,N5,Z
100 END
```

PROGRAM ON $f_7$ KEY

```
10 DISP "PROFILE NUMBER(0-99)";
20 INPUT N5
30 PRINT
40 PRINT "PROFILE",N5
50 PRINT
60 DISP "HORZ GRAPH LIMIT(FT)";
70 INPUT X0
80 SCALE 0,1.2*X0,0,1.2*X0
90 PEN
100 OFFSET 0.1*X0,0.65*X0
110 PLOT 0,0,-2
120 PLOT 0,0,1
130 LABEL (*,2,1.7,0,7/11)
140 CPLOT 0,2
150 LABEL (*,2,1.7,0,7/11)N5
160 PLOT 0,0,1
170 LABEL (*,1,1.7,0,7/11)
180 CPLOT 0,-2
190 LABEL (*,1,1.7,0,7/11)"1"
200 CPLOT 0,3
210 PRINT "TERRAIN"
220 PRINT " POINT        X COORD        Y COORD"
230 PRINT
240 DISP "INITIAL STATION, INITIAL ELEV";
250 INPUT A1,A2
260 N1=1
270 PRINT N1,A1,A2
280 U[N1]=A1
290 V[N1]=A2
300 DISP "ENTER X,Y";
310 INPUT X,Y
320 N1=N1+1
330 U[N1]=X
340 V[N1]=Y
350 H9=X-A1
360 V9=Y-A2
370 PRINT N1,X,Y
380 LABEL (*,1,1.7,0,7/11)
390 PLOT H9,V9,2
400 CPLOT -1,-2
410 LABEL (*,1,1.7,0,7/11)N1
420 CPLOT 1,3
430 GOTO 300
440 STOP
450 END
```

PROGRAM ON $f_8$ KEY

```
10 DISP "PROFILE NUMBER(0-99)";
20 INPUT N5
30 PRINT
40 PRINT "PROFILE",N5
50 PRINT
60 DISP "HORZ GRAPH LIMIT(FT)";
70 INPUT X0
80 SCALE 0,1.2*X0,0,1.2*X0
90 PEN
100 OFFSET 0.1*X0,0.65*X0
110 PLOT 0,0,-2
120 PLOT 0,0,1
130 LABEL (*,2,1.7,0,7/11)
140 CPLOT 0,2
150 LABEL (*,2,1.7,0,7/11)N5
160 PLOT 0,0,1
170 LABEL (*,1,1.7,0,7/11)
180 CPLOT 0,-2
190 LABEL (*,1,1.7,0,7/11)"1"
200 CPLOT 0,3
210 PRINT "TERRAIN"
220 PRINT " POINT          X COORD          Y COORD          SLOPE DIST       % SLOPE"
230 PRINT
240 DISP "INITIAL STATION, INITIAL ELEV";
250 INPUT A1,A2
260 N1=1
270 PRINT N1,A1,A2
280 U[N1]=A1
290 V[N1]=A2
300 Y1=A2
310 X1=A1
320 DEG
330 DISP "SLOPE DISTANCE, PERCENT SLOPE ";
340 INPUT S,P
350 N1=N1+1
360 P1=ABS(P)/100
370 A=ATN(P1)
380 X=S*COS(A)
390 Y=S*SIN(A)
400 IF P>0 THEN 420
410 Y=-Y
420 X1=X1+X
430 Y1=Y1+Y
440 U[N1]=X1
450 V[N1]=Y1
460 PRINT N1,X1,Y1,S,P
470 H9=X1-A1
480 V9=Y1-A2
490 LABEL (*,1,1.7,0,7/11)
500 PLOT H9,V9,2
510 CPLOT -1,-2
520 LABEL (*,1,1.7,0,7/11)N1
530 CPLOT 1,3
540 GOTO 330
550 STOP
560 END
```

PROGRAM ON $f_9$ KEY

```
10 STANDARD
20 DISP "YARDER NAME";
30 INPUT Y$
40 PRINT
50 PRINT Y$
60 DISP "ALLOWABLE SKYLINE TENSION(LBS)";
70 INPUT T1
80 DISP "ALLOWABLE MAINLINE TENSION(LBS)";
90 INPUT T3
100 DISP "ALLOWABLE HAULBACK TENSION(LBS)";
110 INPUT T2
120 DISP "ALLOWABLE SLACKLINE TENSION LBS";
130 INPUT T0
140 DISP "SKYLINE WT (LBS/FT)";
150 INPUT W1
160 DISP "MAINLINE WT (LBS/FT)";
170 INPUT W3
180 DISP "HAULBACK WT (LBS/FT)";
190 INPUT W2
200 DISP "SLACKLINE WT (LBS/FT)";
210 INPUT W0
220 PRINT
230 PRINT "                     ALLOWABLE      LINE"
240 PRINT "                        LOAD        WEIGHT"
250 WRITE (15,260)T1,W1,T3,W3
260 FORMAT "SKYLINE",6X,F8.0,5X,F6.2,/,"MAINLINE",5X,F8.0,5X,F6.2
270 WRITE (15,280)T2,W2,T0,W0
280 FORMAT "HAULBACK",5X,F8.0,5X,F6.2,/,"SLACKLINE",4X,F8.0,5X,F6.2
290 DISP "HEADSPAR HT (FT)";
300 INPUT H6
310 PRINT
320 PRINT "HEADSPAR HT="H6
330 DISP "STORE YARDER IN FILE#(4-20)";
340 INPUT M
350 STORE  DATA M
360 END
```

# A P P E N D I X

3

# SKYLINE ANALYSIS PROGRAM WITH LOG DRAG

There is one main program and ten subprograms in the Skyline Analysis Program with log drag. The following is a listing of these programs:

## MAIN PROGRAM

```
10 COM Y$[50],T0,T1,T2,T3,W0,W1,W2,W3,H6
20 DIM Z5[50,2],X5[50],Y5[50],D5[100],P5[100],S5[100],V5[100]
30 PRINT
40 PRINT TAB15"*****SKYLINE ANALYSIS PROGRAM WITH LOG DRAG*****"
50 PRINT
60 LOAD  KEY 3
70 I1=0
80 DISP "GO TO SPECIAL FUNCTION KEY F5";
90 STOP
100 END
```

## PROGRAM ON $f_0$ KEY

```
10 FIXED 0
20 DISP "PROFILE NUMBER";
30 INPUT P1
40 LOAD  DATA #5,P1,Z
50 FOR I=1 TO 50
60 X[I]=Z[I,1]
70 Y[I]=Z[I,2]
80 NEXT I
90 N1=1
100 FOR I=2 TO 50
110 IF X[I]=0 THEN 140
120 N1=I
130 NEXT I
140 I1=2
150 DISP "GO TO SPECIAL FUNCTION KEY F5"
160 END
```

## PROGRAM ON $f_1$ KEY

```
10 DISP "LOAD YARDER DATA FROM FILE#";
20 INPUT F1
30 LOAD  DATA F1
40 DISP "GO TO SPECIAL FUNCTION KEY F5"
50 END
```

## PROGRAM ON $f_2$ KEY

```
10 DISP "TAILSPAR HT";
20 INPUT H7
30 DISP "HEADSPAR T.P.#,TAILSPAR T.P.#";
40 INPUT S1,S2
50 DISP "GO TO SPECIAL FUNCTION KEY F5"
60 END
```

## PROGRAM ON $f_3$ KEY

```
0 DISP "LENGTH OF LOG(FT)";
0 INPUT L3
0 DISP "LENGTH OF CHOKER(FT)";
0 INPUT L1
0 DISP "GO TO SPECIAL FUNCTION KEY F5"
0 END
```

## PROGRAM ON $f_4$ KEY

```
.0 DISP "LOG TO GROUND CLEARANCE";
20 INPUT C
30 DISP "TERRIAN POINT STEP SIZE";
40 INPUT S5
50 DISP "GO TO SPECIAL FUNCTION KEY F5"
60 END
```

## PROGRAM ON $f_5$ KEY

```
10 STANDARD
20 DEG
30 D3=2
40 F=E3=0
50 N5=3
60 U4=90000
70 U=0.6
80 R4=1
85 C8=0.5
90 PRINT
100 PRINT
110 DISP "LIVE-1,STAND-2,BOTH-3,RUN-4 SKY";
120 INPUT R
130 GOTO R OF 140,160,180,200
140 PRINT "LIVE SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)"
150 GOTO 220
160 PRINT "STANDING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)"
170 GOTO 220
180 PRINT "LIVE AND STANDING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)"
190 GOTO 220
200 PRINT "RUNNING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)"
210 R4=2
220 IF I1#0 THEN 260
230 DISP "LOAD YARDER DATA FROM FILE#";
240 INPUT F1
250 LOAD  DATA F1
260 PRINT
270 PRINT "YARDER SPECS.-"Y$
280 PRINT "                    ALLOWABLE     LINE"
290 PRINT "                       LOAD      WEIGHT"
300 WRITE (15,310)T1,W1,T3,W3
```

```
310 FORMAT "SKYLINE",6X,F8.0,5X,F6.2,/,"MAINLINE",5X,F8.0,5X,F6.2
320 WRITE (15,330)T2,W2,T0,W0
330 FORMAT "HAULBACK",5X,F8.0,5X,F6.2,/,"SLACKLINE",4X,F8.0,5X,F6.2
340 PRINT "HEADSPAR HT="H6
350 IF I1#0 THEN 380
360 DISP "PROFILE NUMBER";
370 INPUT P1
380 PRINT
390 WRITE (15,400)P1
400 FORMAT "PROFILE",F5.0
410 IF I1#0 THEN 520
420 LOAD  DATA #5,P1,Z
430 FOR I=1 TO 50
440 X[I]=Z[I,1]
450 Y[I]=Z[I,2]
460 NEXT I
470 N1=1
480 FOR I=2 TO 50
490 IF X[I]=0 THEN 520
500 N1=I
510 NEXT I
520 DISP "WANT PROFILE PLOTTED";
530 INPUT P5
540 IF P5=0 THEN 870
550 G1=G2=Y[1]
560 FOR I=2 TO N1
570 IF Y[I]>G1 THEN 590
580 G1=Y[I]
590 IF Y[I]<G2 THEN 610
600 G2=Y[I]
610 NEXT I
620 G3=ABS(X[N1]-X[1])
630 G4=1.2*G3
640 G5=1.2*(G2-G1+150)
650 IF (8*G4/10.5)<G5 THEN 680
660 G5=G4*8/10.5
670 GOTO 690
680 G4=G5*10.5/8
690 G6=X[1]-(G4-G3)/2
700 G7=G1-(G5-G2+G1-150)/2
710 SCALE G6,G6+G4,G7,G7+G5
720 PLOT X[1],Y[1],1
730 LABEL (*,2,1.7,0,7/11)
740 CPLOT 0,2
750 LABEL (*,2,1.7,0,7/11)P1
760 PLOT X[1],Y[1],1
770 LABEL (*,1,1.7,0,7/11)
780 CPLOT -0.3,-2
790 LABEL (*,1,1.7,0,7/11)"1"
800 PLOT X[1],Y[1],1
810 FOR I=2 TO N1
820 PLOT X[I],Y[I],2
830 CPLOT -1,-2
840 LABEL (*,1,1.7,0,7/11)I
850 PLOT X[I],Y[I],1
```

```
860 NEXT I
870 IF I1#0 THEN 920
880 DISP "CARRIAGE WT (LB)";
890 INPUT W5
900 DISP "TAILSPAR HT";
910 INPUT H7
920 WRITE (15,930)W5,H7
930 FORMAT "CARRIAGE WT=",2X,F7.0,9X,"TAILSPAR HT=",2X,F5.0
940 IF I1=1 THEN 970
950 DISP "HEADSPAR T.P.#,TAILSPAR T.P.#";
960 INPUT S1,S2
970 PRINT "HEADSPAR T.P. =    "S1;"        TAILSPAR T.P. =  "S2
980 DISP "WANT DATA PLOTTED";
990 INPUT P5
1000 X1=X3=(X[INT(S1)+1]-X[INT(S1)])*(S1-INT(S1))+X[INT(S1)]
1010 Y3=(Y[INT(S1)+1]-Y[INT(S1)])*(S1-INT(S1))+Y[INT(S1)]
1020 X2=X4=(X[INT(S2)+1]-X[INT(S2)])*(S2-INT(S2))+X[INT(S2)]
1030 Y4=(Y[INT(S2)+1]-Y[INT(S2)])*(S2-INT(S2))+Y[INT(S2)]
1040 Y1=Y3+H6
1050 Y2=Y4+H7
1060 L=X4-X3
1070 H=Y1-Y2
1080 IF P5=0 THEN 1140
1090 PLOT X3,Y3,1
1100 PLOT X1,Y1,2
1110 PLOT X2,Y2,2
1120 PLOT X4,Y4,2
1130 PLOT X1,Y1,1
1140 IF I1=1 THEN 1170
1150 DISP "INNER YARD LIM,OUTER YARD LIM";
1160 INPUT S3,S4
1170 PRINT "INN YARD LIM=     "S3;"       OUT YARD LIM=   "S4
1180 IF I1#0 THEN 1230
1190 DISP "LENGTH OF CHOKER(FT)";
1200 INPUT L1
1210 DISP "LENGTH OF LOG(FT)";
1220 INPUT L3
1230 WRITE (15,1240)L1,L3
1240 FORMAT "LENGTH OF CHOKER=",F4.0,9X,"LENGTH OF LOG=",F5.0
1250 L2=L3-D3
1260 E5=L2/(L2-C8*L3)
1270 IF I1#0 THEN 1300
1280 DISP "LOG TO GROUND CLEARANCE";
1290 INPUT C
1300 PRINT "MIN LOG TO GROUND CLEARANCE="C
1310 IF I1#0 THEN 1340
1320 DISP "TERRAIN POINT STEP SIZE";
1330 INPUT S5
1340 PRINT "TERRAIN POINT STEP SIZE="S5
1350 FIXED 2
1360 IF R#4 THEN 1560
1370 DISP "MSP-1,O/U WOUND-2,S.ML.-3,CAR.";
1380 INPUT C2
1390 F3=T3
1400 GOTO C2 OF 1410,1460,1510
```

```
1410 PRINT "MSP TYPE CARRIAGE"
1420 W=W0+W3
1430 T=T0+T3
1440 R5=R6=1
1450 GOTO 1590
1460 PRINT "OVER/UNDER WOUND TYPE CARRIAGE"
1470 W=W0+W3
1480 T=T0+T3
1490 R6=R5=1.5
1500 GOTO 1590
1510 PRINT "SINGLE MAINLINE TYPE CARRIAGE"
1520 W=W3
1530 T=T3
1540 R5=0
1550 R6=9000000
1560 IF R#3 THEN 1590
1570 PRINT
1580 PRINT "LIVE SKYLINE PAYLOADS"
1590 X5=(X[INT(S3)]-X[INT(S3)])*(S3-INT(S3))+X[INT(S3)]
1600 X6=(X[INT(S4)]-X[INT(S4)])*(S4-INT(S4))+X[INT(S4)]
1610 IF X6#X4 THEN 1630
1620 X6=X6-10
1630 IF X5#X3 THEN 1650
1640 X5=X5+10
1650 IF S5 >= 1 THEN 1690
1660 S6=1
1670 S7=INT(1/S5)-1
1680 GOTO 1710
1690 S6=INT(S5)
1700 S7=0.1
1710 IF C<L3 THEN 1750
1720 B1=200
1730 L4=C-D3
1740 GOTO 1770
1750 L4=L2
1760 B1=ATN((C/L3)/SQR(1-(C/L3)^2))
1770 IF R=2 THEN 1790
1780 GOSUB 3720
1790 FOR I=INT(S3) TO INT(S4+0.99) STEP S6
1800 X8=X[I]
1810 B=B1
1820 P=ATN((Y[I]-Y[I+1])/(X[I+1]-X[I]))
1830 IF B+P<90 THEN 1850
1840 B=90-P
1850 K=COS(P+B)/(E5*(COS(B)+U*SIN(B)))
1860 C7=(U*COS(P)+SIN(P))*K
1870 C6=1+(U*SIN(P)-COS(P))*K
1880 A=90-ATN(C7/C6)
1890 X7=X8+L2*COS(P+B)+L1*COS(A)
1900 IF X7>X[I+1] THEN 2250
1910 D1=X7-X8
1920 D2=X[I+1]-D1
1930 C1=L4*SIN(P+B)+L1*SIN(A)-D1*SIN(P)
1940 S8=(D2-X[I])/S7-0.001
1950 D5=L3*COS(P+B)
```

```
1960 D=X[I]-D1+D5
1970 IF (X1+D)<X5 THEN 2020
1980 Y=Y[I]-D5*TAN(P)+L2*SIN(P+B)+L1*SIN(A)
1990 U5=SQR(D*D+Y*Y)+SQR((L-D)^2+(Y-H)^2)
2000 IF U4<U5 THEN 2020
2010 U4=U5
2020 FOR X8=X[I] TO D2 STEP S8
2030 IF X8>X6-D1 THEN 2260
2040 IF X8<X5 THEN 2240
2050 Y9=(X8-X[I])/(X[I+1]-X[I])*(Y[I+1]-Y[I])+Y[I]
2060 Y8=Y9+C1
2070 D=X8-X1
2080 Y=Y1-Y8
2090 W4=900000
2100 S9=I+(X8-X[I])/(X[I+1]-X[I])
2110 F=F+1
2120 D[F]=D
2130 P[F]=P
2140 S[F]=S9
2150 V[F]=Y9
2160 GOTO R OF 2190,2210,2190,2170
2170 GOSUB 3220
2180 GOTO 2200
2190 GOSUB 2320
2200 GOSUB 3810
2210 U5=SQR(D*D+Y*Y)+SQR((L-D)^2+(Y-H)^2)
2220 IF U4<U5 THEN 2240
2230 U4=U5
2240 NEXT X8
2250 NEXT I
2260 IF R=1 OR R=4 THEN 2690
2270 IF R#3 THEN 2310
2275 IF P5=0 THEN 2310
2280 PLOT X2,Y2,2
2290 PLOT X1,Y1,1
2300 N5=3
2310 PRINT
2320 PRINT "STANDING SKYLINE PAYLOADS BASED ON A SKYLINE LENGTH OF"U4"FT"
2330 GOSUB 3720
2340 E=U4/SQR(L*L+H*H)
2350 FOR I=1 TO F
2360 D=D[I]
2370 P=P[I]
2380 S9=S[I]
2390 Y9=V[I]
2400 M=E^2+H*H*(E^2-1)/L^2
2410 N=E*(1-2*D/L)
2420 O=(1-2*D/L)^2-H*H*(E*E-1)/L^2
2430 N=(-N+ABS(H)/H*SQR(N*N-M*O))/M
2440 Y=(H*(1+E*N)+L*SQR((E*E-1)*(1-N*N)))/2
2450 Y8=Y1-Y
2460 C1=Y8-Y9
2470 X8=D+X1
2480 IF (L1+L2)>C1 THEN 2540
2490 B=90-P
2500 C7=0
```

```
2510 C6=1
2520 A=90
2530 GOTO 2660
2540 C5=0
2550 K7=C1*SIN(90+P)/(L1+L2)
2560 B=ATN(K7/SQR(1-K7*K7))
2570 K8=COS(P+B)/(COS(B)+U*SIN(B))/E5
2580 C7=(U*COS(P)+SIN(P))*K8
2590 C6=1+(U*SIN(P)-COS(P))*K8
2600 IF ABS(C6-C5)<0.001 THEN 2650
2610 C5=C6
2620 A=90-ATN(C7/C6)
2630 K7=COS(P)/L2*(C1+L1*(COS(A)*TAN(P)-SIN(A)))
2640 GOTO 2560
2650 A=90-ATN(C7/C6)
2660 GOSUB 2820
2670 GOSUB 3810
2680 NEXT I
2690 IF P5=0 THEN 2720
2700 PLOT X2,Y2,2
2710 PEN
2720 15=INT(S1+1)
2730 I6=INT(S2)
2740 L5=SQR((X[I5]-X3)^2+(Y3-Y[I5])^2)+SQR((X4-X[I6])^2+(Y[I6]-Y4)^2)
2750 FOR I=I5 TO (I6-1)
2760 L5=L5+SQR((X[I+1]-X[I])^2+(Y[I]-Y[I+1])^2)
2770 NEXT I
2780 L5=R4*L5+2*(H6+H7)
2790 PRINT "REQUIRED RIGGING LENGTH="L5
2800 I1=1
2810 END
2820 K1=Y/D
2830 K2=(Y-H)/(L-D)
2840 R1=W1*SQR(D*D+Y*Y)
2850 R2=W1*SQR((L-D)^2+(Y-H)^2)
2860 R3=W3*SQR(D*D+Y*Y)
2870 M=1+K2*K2
2880 N=-K2*R2
2890 O=R2*R2/4-(T1-W1*Y)^2
2900 H2=(-N+SQR(N*N-4*M*O))/(2*M)
2910 W7=(H2*(K2+K1)-W5-(R1+R2+R3)/2)/(C6-C7*K1)
2920 M1=((R1+R2+R3)/2+W5)/(K1+K2)
2930 M2=(C6-C7*K1)/(K1+K2)
2940 M3=K1^2-K2^2
2950 M4=1+K1^2
2960 H3=(K1*R3+SQR(K1^2*R3^2-4*M4*(R3^2/4-(T3-W3*Y)^2)))/2/M4
2970 M=M2^2*M3+2*M2*M4*C7+C7^2*M4
2980 N=M2*(2*M3*M1-2*H3*M4-K1*R1+K2*R2)+2*C7*M4*(M1-H3)-C7*K1*R1
2990 O=M1*(M1*M3-2*H3*M4-K1*R1+K2*R2)+H3*(H3*M4+K1*R1)+(R1^2-R2^2)/4
3000 W8=(-N+SQR(N*N-4*M*O))/(2*M)
3010 W4=W7
3020 IF W8<0 THEN 3120
3030 IF W7>0 AND W7<W8 THEN 3120
3040 W4=W8
3050 T8=T3
```

```
060 V4=C6*W4
070 H4=C7*W4
3080 H2=(W5+V4+(R1+R2+R3)/2-H4*K1)/(K1+K2)
3090 T6=SQR(H2^2+(H2*K2-R2/2)^2)
3100 T7=H2/ABS(H2)*(T6+W1*Y)
3110 GOTO 3200
3120 T7=T1
3130 H4=C7*W4
3140 M=K1^2+1
3150 N=-R1*K1
3160 O=R1*R1/4-(T1-W1*Y)^2
3170 H1=(-N+SQR(N*N-4*M*O))/2/M
3180 H3=H2+H4-H1
3190 T8=H3/ABS(H3)*(SQR((H3*K1-R3/2)^2+H3^2)+W3*Y)
3200 RETURN
3210 END
3220 K1=Y/D
3230 K2=(Y-H)/(L-D)
3240 R1=W2*SQR(D*D+Y*Y)
3250 R2=W2*SQR((L-D)^2+(Y-H)^2)
3260 R3=W*SQR(D*D+Y*Y)
3270 M=1+K2*K2
3280 N=-K2*R2
3290 O=R2*R2/4-(T2-W2*Y)^2
3300 H2=(-N+SQR(N*N-4*M*O))/(2*M)
3310 W7=(2*H2*(K2+K1)-W5-(R1+2*R2+R3)/2)/(C6-C7*K1)
3320 M1=((R1+2*R2+R3)/2+W5)/(2*(K1+K2))
3330 M2=(C6-C7*K1)/(2*(K1+K2))
3340 M3=4*K1^2-K2^2+3
3350 M4=1+K1^2
3360 H3=(K1*R3+SQR(K1^2*R3^2-4*M4*(R3^2/4-(T-W*Y)^2)))/2/M4
3370 M=M2^2*M3+4*M2*M4*C7+C7^2*M4
3380 N=M2*(2*M3*M1-4*H3*M4-2*K1*R1+K2*R2)+2*C7*M4*(2*M1-H3)-C7*K1*R1
3390 O=M1*(M1*M3-4*H3*M4-2*K1*R1+K2*R2)+H3*(H3*M4+K1*R1)+(R1^2-R2^2)/4
3400 W8=(-N+SQR(N*N-4*M*O))/(2*M)
3410 IF C2=3 THEN 3490
3420 F4=T3-((T-W*Y)*R6+R5*W8*SQR(C6^2+C7^2))/(1+R6)-W3*Y
3430 IF ABS(F4)<100 THEN 3490
3440 E4=T
3450 T=E4-F4*(E4-E3)/(F4-F3)
3460 E3=E4
3470 F3=F4
3480 GOTO 3360
3490 W4=W7
3500 IF W8<0 THEN 3600
3510 IF W7>0 AND W7<W8 THEN 3600
3520 W4=W8
3530 T8=T3
3540 V4=C6*W4
3550 H4=C7*W4
3560 H2=(W5+V4+(R1+2*R2+R3)/2-H4*K1)/(2*(K1+K2))
3570 T6=SQR(H2^2+(H2*K2-R2/2)^2)
3580 T7=H2/ABS(H2)*(T6+W2*Y)
3590 GOTO 3700
3600 T7=T2
```

```
3610 V4=C6*W4
3620 H4=C7*W4
3630 M=K1^2+1
3640 N=-R1*K1
3650 O=R1*R1/4-(T2-W2*Y)^2
3660 H1=(-N+SQR(N*N-4*M*O))/2/M
3670 H3=2*H2+H4-H1
3680 T9=H3/ABS(H3)*(SQR((H3*K1-R3/2)^2+H3^2))
3690 T8=(T9*R6+R5*SQR(V4^2+H4^2))/(1+R6)+W3*Y
3700 RETURN
3710 END
3720 PRINT
3730 IF R=4 THEN 3760
3740 PRINT "TERRAIN HORZ  MAX LOG  SKYLINE   MAINLINE   CARRIAGE  LOG TO GROU
3750 GOTO 3770
3760 PRINT "TERRAIN HORZ  MAX LOG  HAULBACK  MAINLINE   CARRIAGE  LOG TO GROU
3770 PRINT " POINT  DIST   LOAD    TENSION   TENSION    CLEARANCE     ANGLE"
3780 PRINT
3790 RETURN
3800 END
3810 WRITE (15,3820)S9,D,W4,T7,T8,C1,B
3820 FORMAT F5.1,2X,F5.0,1X,F7.0,2X,F7.0,3X,F7.0,5X,F7.2,5X,F7.2
3830 IF P5=0 THEN 3920
3840 PLOT X8,Y8,2
3850 IF N5#3 THEN 3910
3860 IPLOT L1*COS(A),-L1*SIN(A),2
3870 IPLOT -D3*COS(P+B),D3*SIN(P+B),2
3880 IPLOT L3*COS(P+B),-L3*SIN(P+B),2
3890 PLOT X8,Y8,1
3900 N5=0
3910 N5=N5+1
3920 RETURN
3930 END
```

PROGRAM ON $f_6$ KEY

```
10 DISP "CARRIAGE WT.";
20 INPUT W5
30 DISP "GO TO SPECIAL FUNCTION KEY F5"
40 END
```

PROGRAM ON $f_7$ KEY

```
10 I1=0
20 DISP "GO TO SPECIAL FUNCTION KEY F5"
30 END
```

## PROGRAM ON $f_8$ KEY

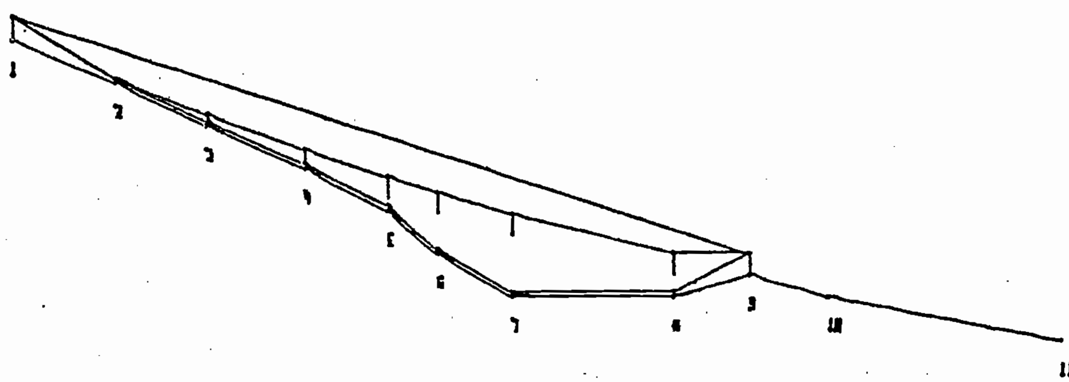
```
10 DISP "INNER YARD LIM,OUTER YARD LIM";
20 INPUT S3,S4
30 DISP "GO TO SPECIAL FUNCTION KEY F5"
40 END
```

## PROGRAM ON $f_9$ KEY

```
10 FIXED 0
20 PRINT
30 PRINT "PROFILE"P1
40 PRINT "T.P.#            X COORD          Y COORD";
50 PRINT
60 FOR I=1 TO N1
70 PRINT I,X[I],Y[I]
80 NEXT I
90 PRINT
100 END
```

# APPENDIX

# 4




LIVE AND STANDING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)

YARDER SPECS. -THUNDERBIRD MOBILE YARDER

| | ALLOWABLE LOAD | LINE WEIGHT |
|---|---|---|
| SKYLINE | 34500 | 1.85 |
| MAINLINE | 19600 | 1.04 |
| HAULBACK | 0 | 0.00 |
| SLACKLINE | 0 | 0.00 |

HEADSPAR HT= 45

PROFILE 14

| | | | |
|---|---|---|---|
| CARRIAGE WT= | 600 | TAILSPAR HT= | 40 |
| HEADSPAR T.P. = | 1 | TAILSPAR T.P. = | 9 |
| INN YARD LIM= | 1 | OUT YARD LIM= | 9 |
| LENGTH OF CHOKER= | 8 | LENGTH OF LOG= | 32 |

MIN LOG TO GROUND CLEARANCE= 2
TERRAIN POINT STEP SIZE= 1

LIVE SKYLINE PAYLOADS

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 15141 | 34500 | 10026 | 8.67 | 3.58 |
| 3.0 | 386 | 13383 | 34500 | 8554 | 8.51 | 3.58 |
| 4.0 | 581 | 12609 | 34500 | 8055 | 8.88 | 3.58 |
| 5.0 | 746 | 13284 | 34500 | 8448 | 11.68 | 3.58 |
| 6.0 | 847 | 24973 | 34500 | 14792 | 9.20 | 3.58 |
| 7.0 | 997 | 47373 | 34500 | 18088 | 9.06 | 3.58 |
| 8.0 | 1322 | 51380 | 34500 | 7164 | 9.94 | 3.58 |

STANDING SKYLINE PAYLOADS BASED ON A SKYLINE LENGTH OF 1548.43 FT

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 14697 | 34500 | 9623 | 8.67 | 5.40 |
| 3.0 | 386 | 7900 | 34500 | 4434 | 21.29 | 26.71 |
| 4.0 | 581 | 4869 | 34500 | 2149 | 35.78 | 57.18 |
| 5.0 | 746 | 4315 | 34500 | 1736 | 64.69 | 51.49 |
| 6.0 | 847 | 4323 | 34500 | 1708 | 115.48 | 62.01 |
| 7.0 | 997 | 4611 | 34500 | 1720 | 154.48 | 90.00 |
| 8.0 | 1322 | 8168 | 34500 | 1862 | 81.67 | 104.57 |

REQUIRED RIGGING LENGTH= 1765.16

Figure 17. Basic Output.

LIVE AND STANDING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)

YARDER SPECS. -THUNDERBIRD MOBILE YARDER

| | ALLOWABLE LOAD | LINE WEIGHT |
|---|---|---|
| SKYLINE | 34500 | 1.85 |
| MAINLINE | 19600 | 1.04 |
| HAULBACK | 0 | 0.00 |
| SLACKLINE | 0 | 0.00 |

HEADSPAR HT= 45

PROFILE 14
CARRIAGE WT= 600 TAILSPAR HT= 40
HEADSPAR T.P. = 1 TAILSPAR T.P. = 9
INN YARD LIM= 1 OUT YARD LIM= 9
LENGTH OF CHOKER= 8 LENGTH OF LOG= 16
MIN LOG TO GROUND CLEARANCE= 2
TERRAIN POINT STEP SIZE= 1

LIVE SKYLINE PAYLOADS

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 13472 | 34500 | 8492 | 8.46 | 7.18 |
| 3.0 | 386 | 11920 | 34500 | 7240 | 8.41 | 7.18 |
| 4.0 | 581 | 11430 | 34500 | 6879 | 8.54 | 7.18 |
| 5.0 | 746 | 12627 | 34500 | 7413 | 9.86 | 7.18 |
| 6.0 | 847 | 22609 | 34500 | 12372 | 8.68 | 7.18 |
| 7.0 | 997 | 40679 | 34500 | 14645 | 9.18 | 7.18 |
| 8.0 | 1322 | 45762 | 34500 | 5584 | 9.94 | 7.18 |

STANDING SKYLINE PAYLOADS BASED ON A SKYLINE LENGTH OF 1548.49 FT

| TERRAIN POIN1 | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 13162 | 34500 | 8210 | 8.46 | 9.03 |
| 3.0 | 386 | 5901 | 34500 | 2609 | 21.03 | 60.76 |
| 4.0 | 581 | 4615 | 34500 | 1881 | 35.50 | 64.19 |
| 5.0 | 746 | 4340 | 34500 | 1743 | 64.40 | 51.49 |
| 6.0 | 847 | 4348 | 34500 | 1714 | 115.20 | 62.01 |
| 7.0 | 997 | 4638 | 34500 | 1726 | 154.22 | 90.00 |
| 8.0 | 1322 | 8208 | 34500 | 1863 | 81.51 | 104.57 |

REQUIRED RIGGING LENGTH= 1765.16

Figure 18. Output for a Log Length of 16 Feet.

LIVE AND STANDING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)

YARDER SPECS. -THUNDERBIRD MOBILE YARDER

| | ALLOWABLE LOAD | LINE WEIGHT |
|---|---|---|
| SKYLINE | 34500 | 1.65 |
| MAINLINE | 19600 | 1.04 |
| HAULBACK | 0 | 0.00 |
| SLACKLINE | 0 | 0.00 |

HEADSPAR HT= 45

PROFILE 14

| | | | |
|---|---|---|---|
| CARRIAGE WT= | 600 | TAILSPAR HT= | 40 |
| HEADSPAR T.P. = | 1 | TAILSPAR T.P. = | 9 |
| INN YARD LIM= | 1 | OUT YARD LIM= | 9 |
| LENGTH OF CHOKER= | 8 | LENGTH OF LOG= | 48 |

MIN LOG TO GROUND CLEARANCE= 2
TERRAIN POINT STEP SIZE= 1

LIVE SKYLINE PAYLOADS

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 15650 | 34500 | 10530 | 9.10 | 2.39 |
| 3.0 | 386 | 13887 | 34500 | 9026 | 8.84 | 2.39 |
| 4.0 | 581 | 12984 | 34500 | 8458 | 9.44 | 2.39 |
| 5.0 | 746 | 13324 | 34500 | 8705 | 13.72 | 2.39 |
| 6.0 | 847 | 25789 | 34500 | 15674 | 9.94 | 2.39 |
| 7.0 | 997 | 50075 | 34500 | 19478 | 9.00 | 2.39 |
| 8.0 | 1322 | 53510 | 34500 | 7754 | 9.84 | 2.39 |

STANDING SKYLINE PAYLOADS BASED ON A SKYLINE LENGTH OF 1548.33 FT

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 15148 | 34500 | 10073 | 9.10 | 4.22 |
| 3.0 | 386 | 8600 | 34500 | 5102 | 21.82 | 18.21 |
| 4.0 | 581 | 5747 | 34500 | 3060 | 36.35 | 35.12 |
| 5.0 | 746 | 4262 | 34500 | 1721 | 65.27 | 51.49 |
| 6.0 | 847 | 4269 | 34500 | 1694 | 116.05 | 62.01 |
| 7.0 | 997 | 4555 | 34500 | 1709 | 155.01 | 90.00 |
| 8.0 | 1322 | 8085 | 34500 | 1858 | 82.01 | 104.57 |

REQUIRED RIGGING LENGTH= 1765.16

Figure 19. Output for a Log Length of 48 Feet.

LIVE AND STANDING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)

YARDER SPECS. -THUNDERBIRD MOBILE YARDER

| | ALLOWABLE LOAD | LINE WEIGHT |
|---|---|---|
| SKYLINE | 34500 | 1.85 |
| MAINLINE | 19600 | 1.04 |
| HAULBACK | 0 | 0.00 |
| SLACKLINE | 0 | 0.00 |

HEADSPAR HT= 45

PROFILE 14

CARRIAGE WT= 600 TAILSPAR HT= 40

HEADSPAR T.P.= 1 TAILSPAR T.P.= 9

INN YARD LIM= 1 OUT YARD LIM= 9

LENGTH OF CHOKER= 8 LENGTH OF LOG= 32

MIN LOG TO GROUND CLEARANCE= 10

TERRAIN POINT STEP SIZE= 1

LIVE SKYLINE PAYLOADS

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 9597 | 34500 | 5800 | 17.52 | 18.21 |
| 3.0 | 386 | 9356 | 34500 | 5495 | 17.27 | 18.21 |
| 4.0 | 581 | 9271 | 34500 | 5358 | 17.83 | 18.21 |
| 5.0 | 746 | 10433 | 34500 | 5661 | 21.25 | 18.21 |
| 6.0 | 847 | 19579 | 34500 | 10063 | 18.26 | 18.21 |
| 7.0 | 997 | 38098 | 34500 | 13658 | 16.85 | 18.21 |
| 8.0 | 1322 | 44416 | 34500 | 6088 | 17.69 | 18.21 |

STANDING SKYLINE PAYLOADS BASED ON A SKYLINE LENGTH OF 1546.47 FT

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 9431 | 34500 | 5647 | 17.52 | 19.84 |
| 3.0 | 386 | 4998 | 34500 | 2485 | 32.14 | 49.50 |
| 4.0 | 581 | 3468 | 34500 | 1513 | 47.61 | 64.19 |
| 5.0 | 746 | 3227 | 34500 | 1435 | 76.64 | 51.49 |
| 6.0 | 847 | 3227 | 34500 | 1433 | 127.23 | 62.01 |
| 7.0 | 997 | 3459 | 34500 | 1481 | 165.48 | 90.00 |
| 8.0 | 1322 | 6455 | 34500 | 1763 | 88.65 | 104.57 |

REQUIRED RIGGING LENGTH= 1765.16

Figure 20. Output for a 10 Foot Minimum Log to Ground Clearance.

IVE AND STANDING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)

ARDER SPECS. -THUNDERBIRD MOBILE YARDER

| | ALLOWABLE LOAD | LINE WEIGHT |
|---|---|---|
| :KYLINE | 34500 | 1.85 |
| 1AINLINE | 19600 | 1.04 |
| 1AULBACK | 0 | 0.00 |
| :LACKLINE | 0 | 0.00 |

1EADSPAR HT= 45

PROFILE 14

CARRIAGE WT= 600 TAILSPAR HT= 40
HEADSPAR T.P. = 1 TAILSPAR T.P. = 9
INN YARD LIM= 1 OUT YARD LIM= 9
LENGTH OF CHOKER= 8 LENGTH OF LOG= 32
MIN LOG TO GROUND CLEARANCE= 30
TERRAIN POINT STEP SIZE= 1

LIVE SKYLINE PAYLOADS

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 2405 | 34500 | 1126 | 38.00 | 65.98 |
| 3.0 | 386 | 3582 | 34500 | 1566 | 38.00 | 67.68 |
| 4.0 | 581 | 4378 | 34500 | 1804 | 38.00 | 64.19 |
| 5.0 | 746 | 6754 | 34500 | 2421 | 38.00 | 51.49 |
| 6.0 | 847 | 11595 | 34500 | 3458 | 38.00 | 62.01 |
| 7.0 | 997 | 21897 | 34500 | 6152 | 36.06 | 69.64 |
| 8.0 | 1322 | 28614 | 34500 | 3786 | 37.12 | 69.64 |

STANDING SKYLINE PAYLOADS BASED ON A SKYLINE LENGTH OF 1543.16 FT

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 2405 | 34500 | 1126 | 38.00 | 65.98 |
| 3.0 | 386 | 1326 | 34500 | 794 | 57.51 | 67.68 |
| 4.0 | 581 | 850 | 34500 | 739 | 75.44 | 64.19 |
| 5.0 | 746 | 681 | 34500 | 794 | 104.88 | 51.49 |
| 6.0 | 847 | 658 | 34500 | 852 | 155.02 | 62.01 |
| 7.0 | 997 | 751 | 34500 | 962 | 191.59 | 90.00 |
| 8.0 | 1322 | 2346 | 34500 | 1337 | 105.28 | 104.57 |

REQUIRED RIGGING LENGTH= 1765.16

Figure 21. Output for a 30 Foot Minimum Log to Ground Clearance.

LIVE AND STANDING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)

YARDER SPECS. -THUNDERBIRD MOBILE YARDER

| | ALLOWABLE LOAD | LINE WEIGHT |
|---|---|---|
| SKYLINE | 34500 | 1.85 |
| MAINLINE | 19600 | 1.04 |
| HAULBACK | 0 | 0.00 |
| SLACKLINE | 0 | 0.00 |

HEADSPAR HT= 45

PROFILE 14
CARRIAGE WT= 600 TAILSPAR HT= 40
HEADSPAR T.P.= 1 TAILSPAR T.P.= 9
INN YARD LIM= 1 OUT YARD LIM= 9
LENGTH OF CHOKER= 24 LENGTH OF LOG= 32
MIN LOG TO GROUND CLEARANCE= 2
TERRAIN POINT STEP SIZE= 1

LIVE SKYLINE PAYLOADS

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 10701 | 34500 | 7053 | 19.86 | 3.58 |
| 3.0 | 386 | 10638 | 34500 | 6817 | 19.82 | 3.58 |
| 4.0 | 581 | 10609 | 34500 | 6818 | 19.96 | 3.58 |
| 5.0 | 746 | 11749 | 34500 | 7521 | 22.53 | 3.58 |
| 6.0 | 847 | 22993 | 34500 | 13670 | 20.16 | 3.58 |
| 7.0 | 997 | 43609 | 34500 | 16791 | 23.42 | 3.58 |
| 8.0 | 1322 | 44956 | 34500 | 7217 | 26.42 | 3.58 |

STANDING SKYLINE PAYLOADS BASED ON A SKYLINE LENGTH OF 1546.00 FT

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 10399 | 34500 | 6773 | 19.86 | 5.48 |
| 3.0 | 386 | 5524 | 34500 | 3154 | 35.01 | 27.21 |
| 4.0 | 581 | 3397 | 34500 | 1644 | 50.75 | 55.80 |
| 5.0 | 746 | 2939 | 34500 | 1356 | 79.82 | 51.49 |
| 6.0 | 847 | 2937 | 34500 | 1361 | 130.35 | 62.01 |
| 7.0 | 997 | 3154 | 34500 | 1417 | 168.41 | 90.00 |
| 8.0 | 1322 | 5996 | 34500 | 1727 | 90.51 | 104.57 |

REQUIRED RIGGING LENGTH= 1765.16

Figure 22. Output for a 24 Foot Choker Length.

```
:VE AND STANDING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)

ARDER SPECS.-THUNDERBIRD MOBILE YARDER
                ALLOWABLE     LINE
                   LOAD       WEIGHT
KYLINF            34500       1.85
AINLINE           19600       1.04
AULBACK               0       0.00
LACKLINE              0       0.00
IEADSPAR HT= 45

PROFILE   14
CARRIAGE WT=        600        TAILSPAR HT=      40
HEADSPAR T.P.=        1        TAILSPAR T.P.=    9
INN YARD LIM=         1        OUT YARD LIM=     9
LENGTH OF CHOKER=     8        LENGTH OF LOG=    32
MIN LOG TO GROUND CLEARANCE= 2
TERRAIN POINT STEP SIZE= 1
```

LIVE SKYLINE PAYLOADS

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 8170 | 34500 | 3773 | 9.57 | 3.58 |
| 3.0 | 386 | 7348 | 34500 | 3217 | 9.46 | 3.58 |
| 4.0 | 581 | 7479 | 34500 | 3091 | 9.71 | 3.58 |
| 5.0 | 746 | 9580 | 34500 | 3593 | 11.30 | 3.58 |
| 6.0 | 847 | 15022 | 34500 | 4837 | 9.91 | 3.58 |
| 7.0 | 997 | 21015 | 34500 | 4526 | 9.06 | 3.58 |
| 8.0 | 1322 | 24915 | 34500 | -1763 | 9.00 | 3.58 |

STANDING SKYLINE PAYLOADS BASED ON A SKYLINE LENGTH OF 1548.22 FT

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 8153 | 34500 | 3757 | 9.57 | 5.41 |
| 3.0 | 386 | 5491 | 34500 | 2322 | 22.39 | 51.79 |
| 4.0 | 581 | 4475 | 34500 | 1835 | 36.98 | 64.19 |
| 5.0 | 746 | 4204 | 34500 | 1705 | 65.90 | 51.49 |
| 6.0 | 847 | 4212 | 34500 | 1680 | 116.67 | 62.01 |
| 7.0 | 997 | 4494 | 34500 | 1696 | 155.59 | 90.00 |
| 8.0 | 1322 | 7996 | 34500 | 1855 | 82.38 | 104.57 |

REQUIRED RIGGING LENGTH= 1765.16

Figure 23. Output for $D_3$=15.

IVE AND STANDING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)

ARDER SPECS.-THUNDERBIRD MOBILE YARDER

| | ALLOWABLE LOAD | LINE WEIGHT |
|---|---|---|
| KYLINE | 34500 | 1.85 |
| AINLINE | 19600 | 1.04 |
| AULBACK | 0 | 0.00 |
| LACKLINE | 0 | 0.00 |

EADSPAR HT= 45

ROFILE 14
ARRIAGE WT= 600 TAILSPAR HT= 40
EADSPAR T.P.= 1 TAILSPAR T.P.= 9
NN YARD LIM= 1 OUT YARD LIM= 9
ENGTH OF CHOKER= 8 LENGTH OF LOG= 32
IN LOG TO GROUND CLEARANCE= 2
ERRAIN POINT STEP SIZE= 1

IVE SKYLINE PAYLOADS

| ERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 25489 | 32096 | 19600 | 6.80 | 3.58 |
| 3.0 | 386 | 23789 | 34500 | 17719 | 6.61 | 3.58 |
| 4.0 | 581 | 19937 | 34500 | 15099 | 7.05 | 3.58 |
| 5.0 | 746 | 16997 | 34500 | 13132 | 10.16 | 3.58 |
| 6.0 | 847 | 26494 | 25561 | 19600 | 7.41 | 3.58 |
| 7.0 | 997 | 41208 | 13645 | 19600 | 7.15 | 3.58 |
| 8.0 | 1322 | 89344 | 27215 | 19600 | 9.28 | 3.58 |

TANDING SKYLINE PAYLOADS BASED ON A SKYLINE LENGTH OF 1548.89 FT

| ERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 25899 | 34422 | 19600 | 6.80 | 5.38 |
| 3.0 | 386 | 10750 | 34500 | 6865 | 19.01 | 24.47 |
| 4.0 | 581 | 5665 | 34500 | 2781 | 33.30 | 51.19 |
| 5.0 | 746 | 4543 | 34500 | 1800 | 62.18 | 51.49 |
| 6.0 | 847 | 4553 | 34500 | 1765 | 113.02 | 62.01 |
| 7.0 | 997 | 4853 | 34500 | 1770 | 152.17 | 90.00 |
| 8.0 | 1322 | 8524 | 34500 | 1875 | 80.22 | 104.57 |

EQUIRED RIGGING LENGTH= 1765.16

Figure 24. Output for $C_8$=0.3.

LIVE AND STANDING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)

YARDER SPECS. -THUNDERBIRD MOBILE YARDER

| | ALLOWABLE LOAD | LINE WEIGHT |
|---|---|---|
| SKYLINE | 34500 | 1.85 |
| MAINLINE | 19600 | 1.04 |
| HAULBACK | 0 | 0.00 |
| SLACKLINE | 0 | 0.00 |

HEADSPAR HT= 45

PROFILE 14
CARRIAGE WT= 600 TAILSPAR HT= 40
HEADSPAR T.P.= 1 TAILSPAR T.P.= 9
INN YARD LIM= 1 OUT YARD LIM= 9
LENGTH OF CHOKER= 8 LENGTH OF LOG= 32
MIN LOG TO GROUND CLEARANCE= 2
TERRAIN POINT STEP SIZE= 1

LIVE SKYLINE PAYLOADS

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 10246 | 34500 | 5706 | 10.09 | 3.58 |
| 3.0 | 386 | 9231 | 34500 | 4928 | 9.91 | 3.58 |
| 4.0 | 581 | 9163 | 34500 | 4773 | 10.31 | 3.58 |
| 5.0 | 746 | 10870 | 34500 | 5434 | 13.03 | 3.58 |
| 6.0 | 847 | 18421 | 34500 | 8308 | 10.63 | 3.58 |
| 7.0 | 997 | 28508 | 34500 | 8402 | 9.73 | 3.58 |
| 8.0 | 1322 | 32900 | 34500 | 2049 | 9.86 | 3.58 |

STANDING SKYLINE PAYLOADS BASED ON A SKYLINE LENGTH OF 1548.10 FT

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 10128 | 34500 | 5598 | 10.09 | 5.44 |
| 3.0 | 386 | 6307 | 34500 | 3099 | 23.02 | 28.68 |
| 4.0 | 581 | 4436 | 34500 | 1840 | 37.66 | 62.95 |
| 5.0 | 746 | 4141 | 34500 | 1688 | 66.59 | 51.49 |
| 6.0 | 847 | 4148 | 34500 | 1664 | 117.35 | 62.01 |
| 7.0 | 997 | 4428 | 34500 | 1682 | 156.23 | 90.00 |
| 8.0 | 1322 | 7897 | 34500 | 1850 | 82.78 | 104.57 |

REQUIRED RIGGING LENGTH= 1765.16

Figure 25. Output for $C_8$=0.7.

LIVE AND STANDING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)

YARDER SPECS. -THUNDERBIRD MOBILE YARDER

| | ALLOWABLE LOAD | LINE WEIGHT |
|---|---|---|
| SKYLINE | 34500 | 1.85 |
| MAINLINE | 19600 | 1.04 |
| HAULBACK | 0 | 0.00 |
| SLACKLINE | 0 | 0.00 |

HEADSPAR HT= 45

PROFILE 14
CARRIAGE WT= 600 TAILSPAR HT= 40
HEADSPAR T.P.= 1 TAILSPAR T.P.= 9
INN YARD LIM= 1 OUT YARD LIM= 9
LENGTH OF CHOKER= 8 LENGTH OF LOG= 32
MIN LOG TO GROUND CLEARANCE= 2
TERRAIN POINT STEP SIZE= 1

LIVE SKYLINE PAYLOADS

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 14910 | 34500 | 8705 | 9.05 | 3.58 |
| 3.0 | 386 | 13246 | 34500 | 7416 | 8.90 | 3.58 |
| 4.0 | 581 | 12676 | 34500 | 7133 | 9.24 | 3.58 |
| 5.0 | 746 | 13663 | 34500 | 7862 | 11.92 | 3.58 |
| 6.0 | 847 | 25194 | 34500 | 13069 | 9.53 | 3.58 |
| 7.0 | 997 | 43086 | 34500 | 12529 | 9.46 | 3.58 |
| 8.0 | 1322 | 46287 | 34500 | 2254 | 9.87 | 3.58 |

STANDING SKYLINE PAYLOADS BASED ON A SKYLINE LENGTH OF 1548.34 FT

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 14547 | 34500 | 8433 | 9.05 | 5.43 |
| 3.0 | 386 | 8029 | 34500 | 4141 | 21.75 | 27.32 |
| 4.0 | 581 | 4810 | 34500 | 2071 | 36.28 | 58.63 |
| 5.0 | 746 | 4269 | 34500 | 1723 | 65.19 | 51.49 |
| 6.0 | 847 | 4276 | 34500 | 1696 | 115.97 | 62.01 |
| 7.0 | 997 | 4563 | 34500 | 1710 | 154.94 | 90.00 |
| 8.0 | 1322 | 8096 | 34500 | 1859 | 81.97 | 104.57 |

REQUIRED RIGGING LENGTH= 1765.16

Figure 26. Output for U=0.4.

LIVE AND STANDING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)

YARDER SPECS. -THUNDERBIRD MOBILE YARDER

| | ALLOWABLE LOAD | LINE WEIGHT |
|---|---|---|
| SKYLINE | 34500 | 1.85 |
| MAINLINE | 19600 | 1.04 |
| HAULBACK | 0 | 0.00 |
| SLACKLINE | 0 | 0.00 |

HEADSPAR HT= 45

PROFILE 14
CARRIAGE WT= 600 TAILSPAR HT= 40
HEADSPAR T.P. = 1 TAILSPAR T.P. = 9
INN YARD LIM= 1 OUT YARD LIM= 9
LENGTH OF CHOKER= 8 LENGTH OF LOG= 32
MIN LOG TO GROUND CLEARANCE= 2
TERRAIN POINT STEP SIZE= 1

LIVE SKYLINE PAYLOADS

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 15362 | 34500 | 11347 | 8.34 | 3.58 |
| 3.0 | 386 | 13511 | 34500 | 9682 | 8.17 | 3.58 |
| 4.0 | 581 | 12540 | 34500 | 8943 | 8.57 | 3.58 |
| 5.0 | 746 | 12933 | 34500 | 8989 | 11.47 | 3.58 |
| 6.0 | 847 | 24757 | 34500 | 16444 | 8.90 | 3.58 |
| 7.0 | 997 | 41479 | 28309 | 19600 | 8.61 | 3.58 |
| 8.0 | 1322 | 57654 | 34500 | 13246 | 9.79 | 3.58 |

STANDING SKYLINE PAYLOADS BASED ON A SKYLINE LENGTH OF 1548.51 FT

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | SKYLINE TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 14838 | 34500 | 10791 | 8.34 | 5.37 |
| 3.0 | 386 | 7803 | 34500 | 4695 | 20.89 | 26.17 |
| 4.0 | 581 | 4912 | 34500 | 2218 | 35.34 | 55.95 |
| 5.0 | 746 | 4355 | 34500 | 1747 | 64.24 | 51.49 |
| 6.0 | 847 | 4363 | 34500 | 1718 | 115.04 | 62.01 |
| 7.0 | 997 | 4654 | 34500 | 1729 | 154.07 | 90.00 |
| 8.0 | 1322 | 8231 | 34500 | 1864 | 81.42 | 104.57 |

REQUIRED RIGGING LENGTH= 1765.16

Figure 27. Output for U=0.8.

RUNNING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)

YARDER SPECS.-PSY 200

| | ALLOWABLE LOAD | LINE WEIGHT |
|---|---|---|
| SKYLINE | 0 | 0.00 |
| MAINLINE | 19600 | 1.04 |
| HAULBACK | 19600 | 1.04 |
| SLACKLINE | 19600 | 1.04 |

HEADSPAR HT= 50

PROFILE 14

| | | | |
|---|---|---|---|
| CARRIAGE WT= | 600 | TAILSPAR HT= | 40 |
| HEADSPAR T.P.= | 1 | TAILSPAR T.P.= | 9 |
| INN YARD LIM= | 1 | OUT YARD LIM= | 9 |
| LENGTH OF CHOKER= | 8 | LENGTH OF LOG= | 32 |

MIN LOG TO GROUND CLEARANCE= 2
TERRAIN POINT STEP SIZE= 1
MSP TYPE CARRIAGE

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | HAULBACK TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 15338 | 16263 | 19600 | 8.67 | 3.58 |
| 3.0 | 386 | 14663 | 17911 | 19600 | 8.51 | 3.58 |
| 4.0 | 581 | 13982 | 18381 | 19600 | 8.88 | 3.58 |
| 5.0 | 746 | 13709 | 17612 | 19600 | 11.68 | 3.58 |
| 6.0 | 847 | 17793 | 13197 | 19600 | 9.20 | 3.58 |
| 7.0 | 997 | 27904 | 11273 | 19600 | 9.06 | 3.58 |
| 8.0 | 1322 | 38537 | 13614 | 19600 | 9.94 | 3.58 |

REQUIRED RIGGING LENGTH= 3370.31

Figure 28. Output for MSP Type Carriage.

```
RUNNING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)

YARDER SPECS. -PSY 200
                ALLOWABLE     LINE
                  LOAD       WEIGHT
SKYLINE             0         0.00
MAINLINE        19600         1.04
HAULBACK        19600         1.04
SLACKLINE       19600         1.04
HEADSPAR HT= 50

PROFILE   14
CARRIAGE WT=       600         TAILSPAR HT=      40
HEADSPAR T.P. =     1          TAILSPAR T.P. =   9
INN YARD LIM=       1          OUT YARD LIM=     9
LENGTH OF CHOKER=   8          LENGTH OF LOG=    32
MIN LOG TO GROUND CLEARANCE= 2
TERRAIN POINT STEP SIZE= 1
OVER/UNDER WOUND TYPE CARRIAGE
```

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | HAULBACK TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 12473 | 13972 | 19600 | 8.67 | 3.58 |
| 3.0 | 386 | 11885 | 15393 | 19600 | 8.51 | 3.58 |
| 4.0 | 581 | 11310 | 15785 | 19600 | 8.88 | 3.58 |
| 5.0 | 746 | 11162 | 15122 | 19600 | 11.68 | 3.58 |
| 6.0 | 847 | 14598 | 11399 | 19600 | 9.20 | 3.58 |
| 7.0 | 997 | 23004 | 9761 | 19600 | 9.06 | 3.58 |
| 8.0 | 1322 | 31901 | 11690 | 19600 | 9.94 | 3.58 |

REQUIRED RIGGING LENGTH= 3370.31

Figure 29. Output for Over/Under Wound Carriage with $R_5$=$R_6$=1.5.

```
RUNNING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)

YARDER SPECS. -PSY 200
                ALLOWABLE     LINE
                   LOAD      WEIGHT
SKYLINE              0        0.00
MAINLINE         19600        1.04
HAULBACK         19600        1.04
SLACKLINE        19600        1.04
HEADSPAR HT= 50

PROFILE    14
CARRIAGE WT=        600          TAILSPAR HT=      40
HEADSPAR T.P. =       1          TAILSPAR T.P. =    9
INN YARD LIM=         1          OUT YARD LIM=      9
LENGTH OF CHOKER=     8          LENGTH OF LOG=    32
MIN LOG TO GROUND CLEARANCE= 2
TERRAIN POINT STEP SIZE= 1
OVER/UNDER WOUND TYPE CARRIAGE
```

| TERRAIN POINT | HORZ DIST | MAX LOG LOAD | HAULBACK TENSION | MAINLINE TENSION | CARRIAGE CLEARANCE | LOG TO GROUND ANGLE |
|---|---|---|---|---|---|---|
| 2.0 | 207 | 11041 | 12827 | 19600 | 8.67 | 3.58 |
| 3.0 | 386 | 10497 | 14134 | 19600 | 8.51 | 3.58 |
| 4.0 | 581 | 10039 | 14549 | 19600 | 8.88 | 3.58 |
| 5.0 | 746 | 9888 | 13876 | 19600 | 11.68 | 3.58 |
| 6.0 | 847 | 13000 | 10500 | 19600 | 9.20 | 3.58 |
| 7.0 | 997 | 20551 | 9005 | 19600 | 9.06 | 3.58 |
| 8.0 | 1322 | 28580 | 10728 | 19600 | 9.94 | 3.58 |

REQUIRED RIGGING LENGTH= 3370.31

Figure 30. Output for Over/Under Wound Carriage with $R_5$=$R_6$=2.0.

```
RUNNING SKYLINE LOAD ANALYSIS(RIGID LINK ASSUMPTION)

YARDER SPECS. -PSY 200
                 ALLOWABLE     LINE
                    LOAD      WEIGHT
SKYLINE               0        0.00
MAINLINE          19600        1.04
HAULBACK          19600        1.04
SLACKLINE         19600        1.04
HEADSPAR HT= 50

PROFILE    14
CARRIAGE WT=        600         TAILSPAR HT=      40
HEADSPAR T.P. =      1          TAILSPAR T.P. =   9
INN YARD LIM=        1          OUT YARD LIM=     9
LENGTH OF CHOKER=    8          LENGTH OF LOG=    32
MIN LOG TO GROUND CLEARANCE= 2
TERRAIN POINT STEP SIZE= 1
SINGLE MAINLINE TYPE CARRIAGE

TERRAIN HORZ  MAX LOG  HAULBACK  MAINLINE   CARRIAGE  LOG TO GROUND
 POINT  DIST   LOAD    TENSION   TENSION    CLEARANCE     ANGLE

  2.0    207   10739    12391     19600        8.67         3.58
  3.0    386    9964    13257     19600        8.51         3.58
  4.0    581    9624    13568     19600        8.88         3.58
  5.0    746   10025    13398     19600       11.68         3.58
  6.0    847   14762    11000     19600        9.20         3.58
  7.0    997   25467    10080     19600        9.06         3.58
  8.0   1322   41827    14090     19600        9.94         3.58
REQUIRED RIGGING LENGTH= 3370.31
```

Figure 31. Output for a Single Mainline Type Carriage.

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