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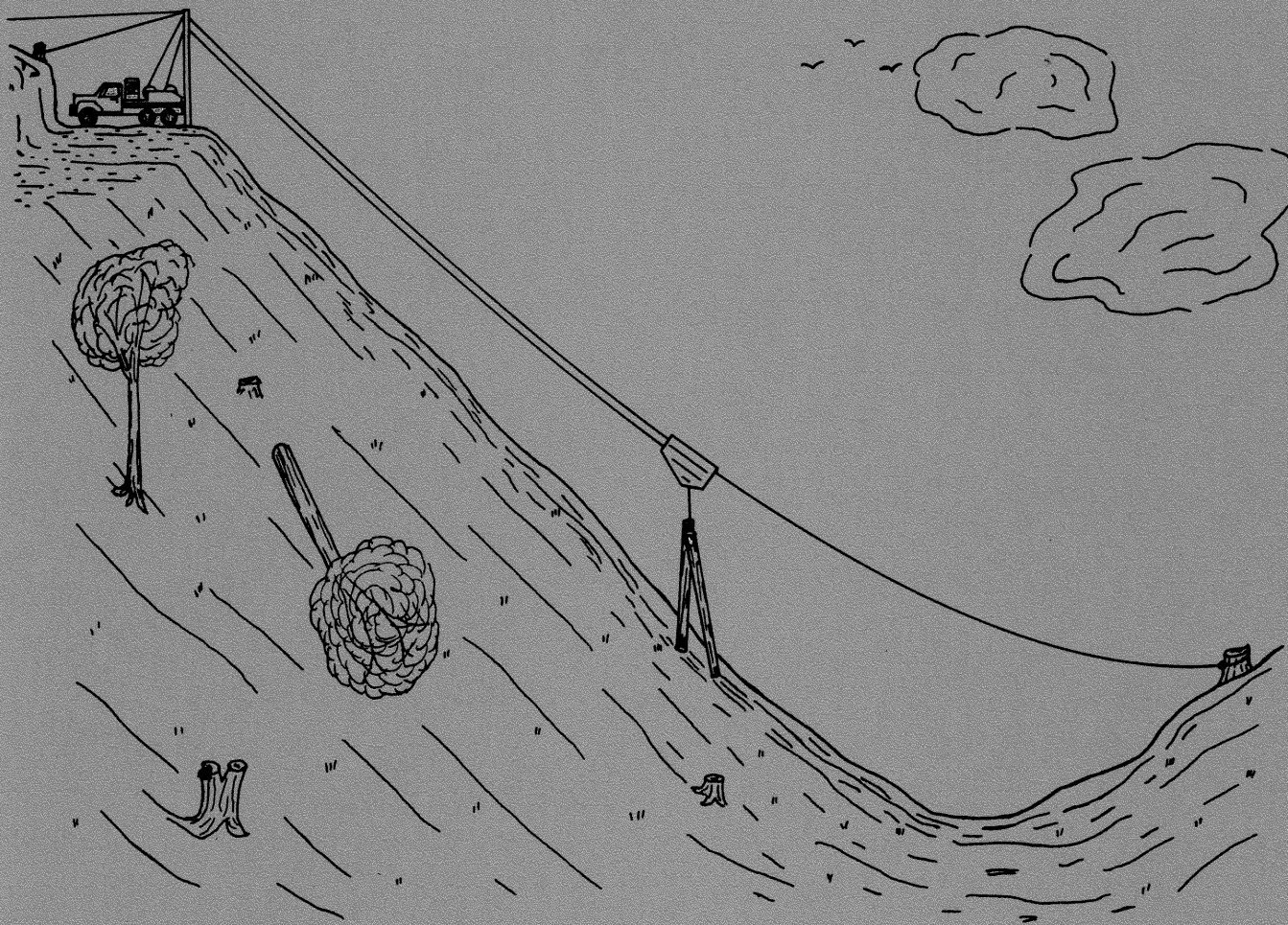
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Predicting the Payload Capability of Cable Logging Systems Including the Effect of Partial Suspension

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Abstract

A systematic procedure for predicting the payload capability of running, live, and standing skylines is presented. Three hand-held calculator programs are used to predict payload capability that includes the effect of partial suspension. The programs allow for predictions for downhill yarding and for yarding away from the yarder. The equations and basic principles involved in analyzing skyline systems for allowable payload are presented.

Predicting the Payload Capability of Cable Logging Systems Including the Effect of Partial Suspension

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Several tools are available for predicting the payload capability of cable logging systems. Hand-held calculator programs (Binkley and Sessions, undated) are among the tools that are capable of yielding the most reliable results with less effort than other hand methods. However, no systematic approach or procedure has been documented for using these programs, which can be followed with relative ease by someone unfamiliar with cable systems mechanics, as there has been for the chain and board method (Lysons and Mann, 1967). Therefore, hand-held calculator programs to determine payload capability are not effectively used by field personnel.

Furthermore, existing programs are based on the assumption that the logs are fully suspended, while actual yarding conditions usually involve partial suspension. The traditional way to account for the effect of partial suspension is to increase the fully suspended payload by a "conservative" 50 percent (Binkley and Sessions, undated). The actual ratio of a partially suspended payload capability to a fully suspended payload capability can range from about 0.5 to 3.5. There are methods to calculate an approximate ratio when the amount of suspension is known, but because the amount of suspension is a function of several variables and not easily determined, these methods of predicting payload capability are not as realistic as they should be, nor are they always conservative.

This paper presents a systematic procedure for predicting the payload capability for the most common skyline yarding systems, by the use of three hand-held calculator programs, that include effect of partial suspension. Because the procedures for predicting the payload capability can be confusing, whether or not partial suspension is considered, the basic principles are also explained. As a result, the user can better understand the purpose of each step of the procedure and increase the effectiveness of this as well as other methods of predicting payload capability.

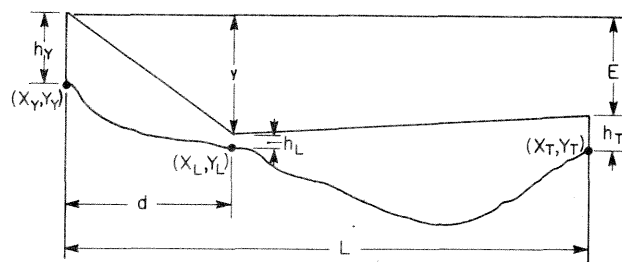
These programs use mathematical formulas based on assumptions that are similar to the so-called "rigid link" (Carson 1976). These formulas have been simplified and extended so that the effects of partial suspension may be included directly. Appendix 4 lists the simplifying assumptions made and the equations used in each of the programs. Because it is not always easy to know when a mainline or haulback is required when partial suspension is considered, the option of a haulback line on live and standing skylines is included. The yarder is assumed to be positioned on the left with stationing increasing toward the right. In addition, the carriage is assumed to be the type in which the mainline is used either to bring the turn to the carriage or to maintain carriage position while the load is brought into position for inhaul.

Description of Variables

The load-carrying capability of a cable logging system depends not only on the size and strength of the cables, but also on the angles at which the cable tensions act at the carriage. These angles depend on the system geometry, which may be thought of as consisting of two parts: the cable geometry which accounts for the deflection, and the log geometry which accounts for the amount of suspension. Regardless of the systems being analyzed, the system geometry must be specified before the payload capability can be determined.

The cable geometry (Fig. 1) is described in two ways. Normally, it is described by the locations of the yarder, tailhold and carriage in terms of X and Y coordinates, and their appropriate heights. These are reduced to the variables L, E, d, and y for the actual calculations. However, when L, E, d, and y are known they may be used directly.

Figure 1.—Cable geometry.

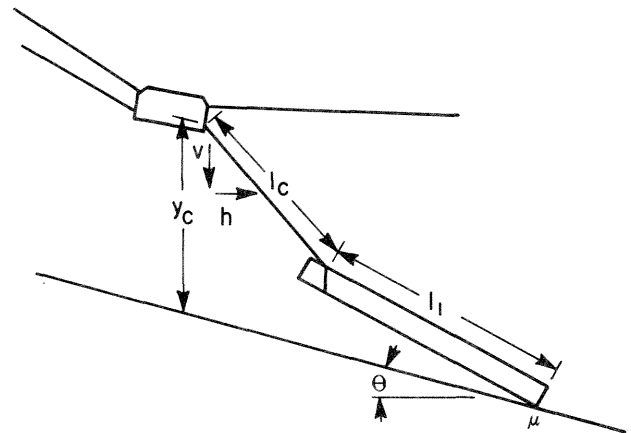


X_Y, Y_Y = X & Y coordinates of yarder spar
 X_T, Y_T = X & Y coordinates of tailhold
 X_L, Y_L = X & Y coordinates of load point
 h_Y, h_T, h_L = Heights of yarder, tailhold, & load clearance
 L = Horizontal distance--yarder to tailhold
 E = Vertical distance--yarder to tailhold
 d = Horizontal distance--yarder to load point
 y = Vertical distance--yarder to load point

The log geometry (Fig. 2) is specified by the friction coefficient, the log and choker lengths, the ground slope, and the carriage clearance. These five variables are used to calculate the partial suspension load factors, v and h , which express the proportion of log weight that is transferred to the carriage as vertical and horizontal force components. For full suspension, v equals 1 and h equals 0.

These diagrams show that as the position of the carriage changes, the cable and the log geometry also change. This results in a different payload capability for each carriage position. In other words, the cable tensions resulting from a

Figure 2.—Log geometry.



μ = Friction coefficient
 l_l = Length of log
 l_c = Length of choker
 θ = Ground slope
 y_c = Carriage clearance
 v = Vertical load factor
 h = Horizontal load factor

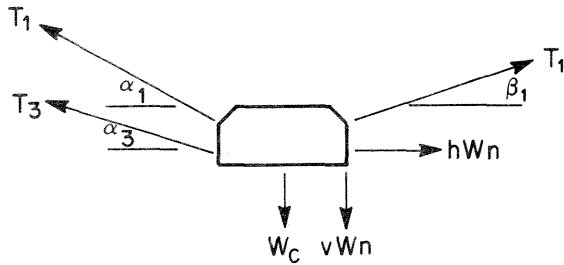
given size and weight log will vary as the carriage is moved along the skyline. Generally, the skyline tension is greater when the load is in the middle of the span, and the mainline or haulback tension is greater when the load is near one end of the span. Because this is a general statement, the payload capability for each line should be calculated for several carriage positions.

The payload capability for a particular carriage position is determined by the analysis of a free-body diagram of the carriage. Figure 3 shows a typical free body for a skyline system with a mainline. The actual forces that act at the carriage depend on the system being analyzed and whether a mainline or haulback is needed to maintain log stability.

The major difficulty in the analyses and the programs that follow is understanding the geometry. When it is known how the cable geometry changes for the different systems and how this affects the log geometry and associated load factors, the analyses become straightforward. As an aid to understanding this concept, each major skyline system (live, running, and standing) in the text is discussed separately and in order of increasing complexity, even though there are similarities among them. After these systems are discussed and

examples are given, methods of using these programs for other yarding configurations are presented.

Figure 3.—Free body of carriage.



T_1 = Tension in skyline

T_3 = Tension in mainline

α_1 = Line of action of skyline to left of carriage

α_3 = Line of action of mainline

β_1 = Line of action of skyline to right of carriage

W_c = Carriage weight

vW_n = Vertical component due to net payload

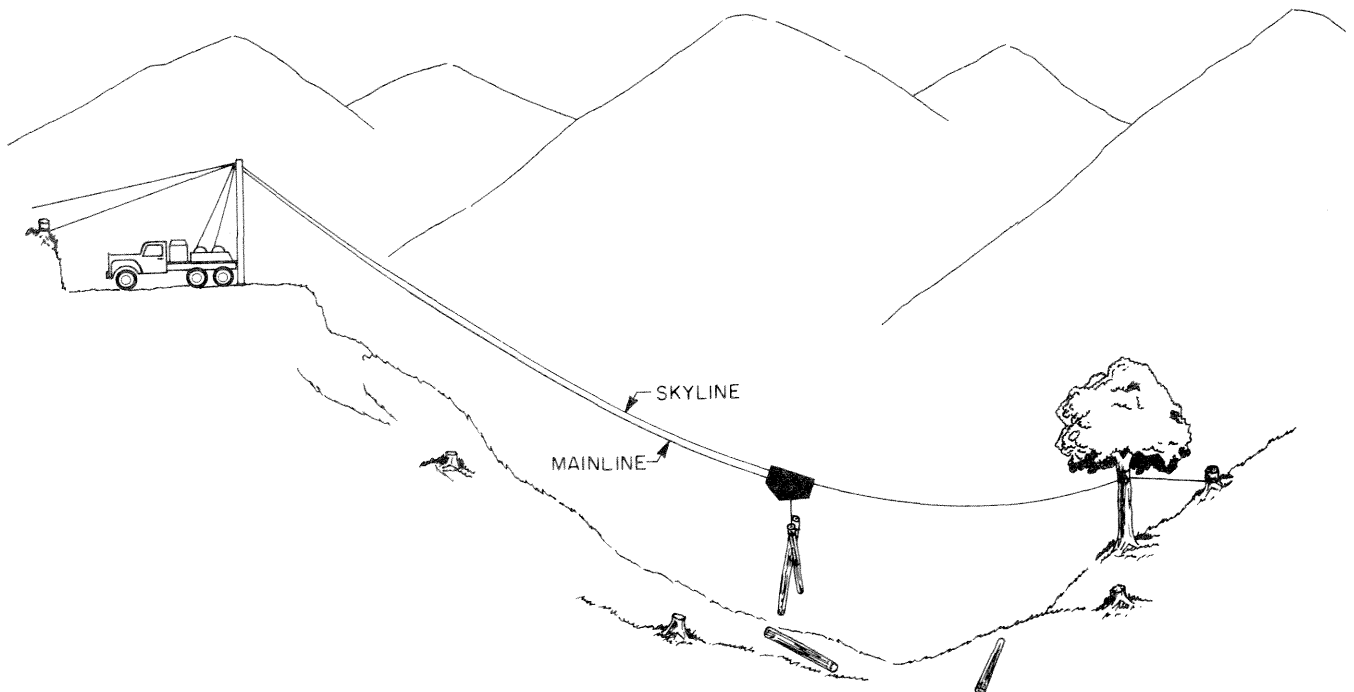
hW_n = Horizontal component due to net payload

The reader should become familiar with these concepts by working the example problems in the appendices before proceeding to the example problems for the different systems.

Live Skyline

Figure 4 depicts a typical live skyline. For convenience, the system is shown with only a mainline although a haul-back may be required. The program considers either case. As discussed here, a live skyline is one in which the length of the skyline is actually varied as the log turn is brought toward the landing. If the skyline length is not varied, then, even though it is traditionally classified as a live skyline, it should be analyzed as a standing skyline. This distinction is important because it determines the cable geometry.

Figure 4.—Live skyline configuration.



Cable Geometry

Since the skyline length varies as the load is brought toward the landing, the load clearance (h_L) is considered to be held constant for each carriage position. Figure 5 traces the carriage at each point along the skyline corridor. The geometry is described by specifying the coordinates and heights of the yarder spar and tailhold, and then specifying each load point in terms of its coordinates and the constant load clearance.

Log Geometry

Since the load clearance, h_L , of the cable geometry remains constant, the carriage height, y_c , also remains constant. For most carriages these two clearances can be taken as the same ($h_L = y_c$), and this assumption is made throughout these discussions and in the programs. However, for very large carriages, the more exact relationship given by equation 1 may be used.

$$h_L = y_c + d_s \quad (1)$$

where d_s = distance separating the skyline and the mainline (or choker) at the carriage. For the live skyline then, the only log geometry parameter that changes significantly from one load point to another is the ground slope.

Procedure

The assumption that the carriage clearance is constant makes the procedure for determining payload capability very straightforward. The two main steps are:

1. Use the "Partial Suspension Load Factors" program (Appendix 2) to determine the partial suspension load factors for each load point for which capability is to be determined.
2. Use the "Partial Suspension Payload (III)" program (Ap-

pendix 3) to determine the allowable payloads for each load point for which capability is to be determined.

The least of these payloads is the one taken to be the maximum load that the system can carry without exceeding any of the allowable tensions.

Example

The profile data of Figure 6A and the data that follow illustrate the procedure.

$\omega_1 = 1.85 \text{ lb/ft}$	$T_1 = 34500 \text{ lb}$	$\mu = 0.60$
$\omega_3 = 0.72 \text{ lb/ft}$	$T_3 = 13700 \text{ lb}$	$l_q = 40 \text{ ft}$
$\omega_4 = 0.46 \text{ lb/ft}$	$T_4 = 8900 \text{ lb}$	$l_c = 16 \text{ ft}$
$W_c = 750 \text{ lb}$		

Yarder location: Terrain point (T.P.) 3, $h_y = 50 \text{ ft}$

Tailhold location: T.P. 10, $h_T = 20 \text{ ft}$

Minimum load clearance: $h_L = y_c = 12 \text{ ft}$

Step 1. Use the "Partial Suspension Load Factors" program (Appendix 2) to determine the load factors.

1. Input $\mu = 0.6$ (Key A)
2. Input $l_q = 40$ and $l_c = 16$ (Key B)
3. For each load point, enter the ground slope (Key C), and then enter the carriage clearance and compute the value for v and h (Key D). The results are:

Terrain point	Input		Output	
	θ	Y_c	v	h
4	0.40	12	0.68	0.42
5	0.20	12	0.58	0.38
6	0.40	12	0.68	0.42
7	0.25	12	0.61	0.39
8	0.40	12	0.68	0.42

Figure 5.—Load path of a live or running skyline.

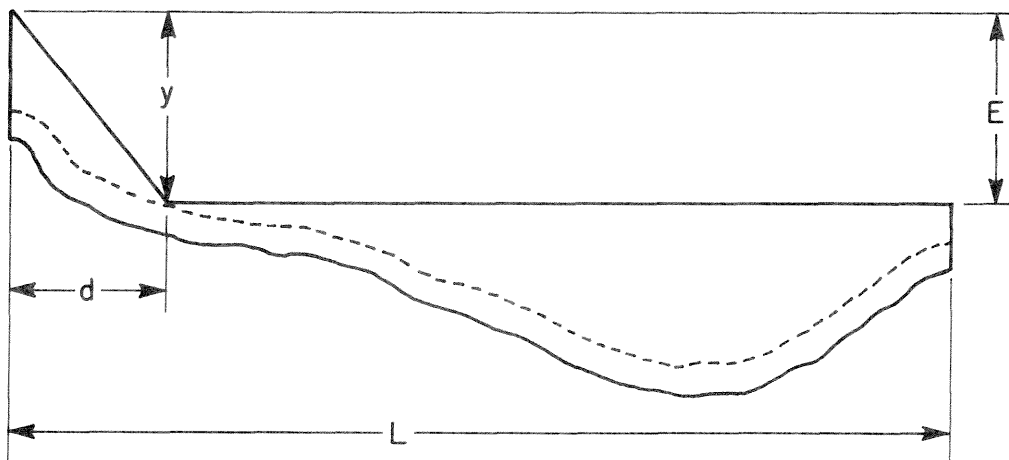
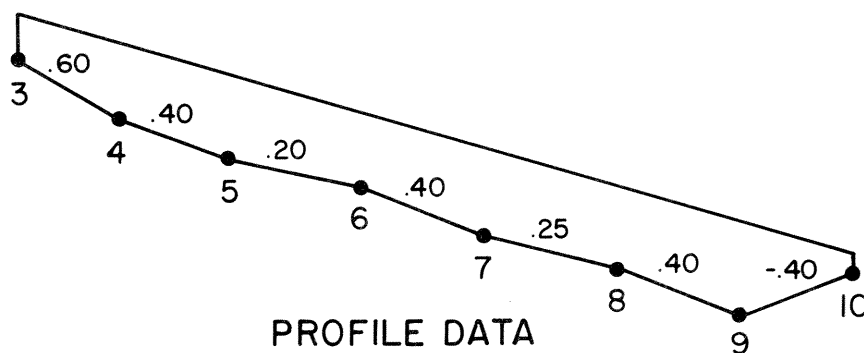


Figure 6.—Profile data in standard form for yarder above tailhold (A) and below tailhold (B).

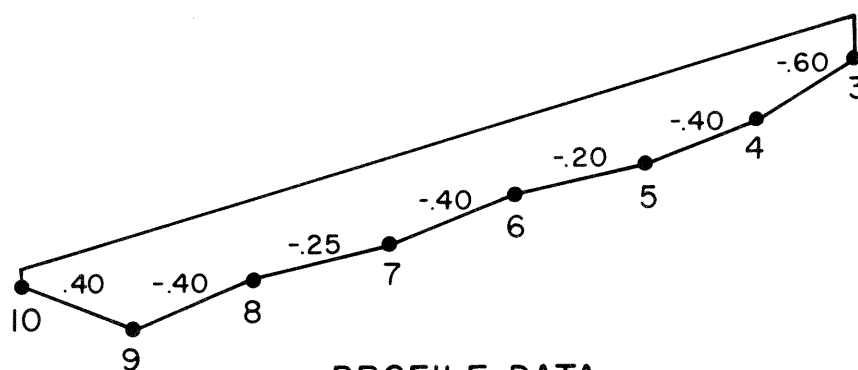
A



PROFILE DATA

TERRAIN POINT	SLOPE DISTANCE	% SLOPE	X COORDINATE	Y COORDINATE
3	125	0.60	568.0	4968.2
4	125	0.40	675.2	4903.9
5	150	0.20	791.2	4857.5
6	135	0.40	938.3	4828.0
7	150	0.25	1063.7	4777.9
8	140	0.40	1209.2	4741.5
9	130	-0.40	1339.2	4689.5
10			1459.9	4737.8

B



PROFILE DATA

TERRAIN POINT	SLOPE DISTANCE	% SLOPE	X COORDINATE	Y COORDINATE
10	130	0.40	000.0	5000.0
9	140	-0.40	120.7	4951.7
8	150	-0.25	250.7	5003.7
7	135	-0.40	396.2	5040.1
6	150	-0.20	521.6	5090.2
5	125	-0.40	668.6	5119.6
4	125	-0.60	784.7	5166.1
3			891.9	5230.4

Step 2. Use the "Partial Suspension Payload III" program (Appendix 3) to determine the allowable payload.

1. Input $T_3 = 13700$
 $\omega_3 = 0.72$
 $T_4 = 8900$ and
 $\omega_4 = 0.46$ (Key A)
2. Input $f = 1$
 $W_c = 750$
 $T_1 = 34500$ and
 $\omega_1 = 1.85$ (Key B)
3. Input $X_Y = 568.0$
 $Y_Y = 4968.2$ and
 $h_Y = 50$ (Key fA)
4. Input $X_T = 1459.9$
 $Y_T = 4737.8$ and
 $h_T = 20$ (Key fB)
5. For each load point, enter the coordinates and carriage clearance (Key fC), and then use Key E to enter the load factors and calculate the allowable payloads based on the allowable skyline tension. Use Key fE to calculate the payload based on allowable mainline tension. The results are:

Terrain point	Input						Output	
	X_L	Y_L	h_L	v	h		$W_n(T_1)$	$W_n(T_3)$
4	675.2	4903.9	12	0.68	0.42		84258.07	18512.13
5	791.2	4857.5	12	0.58	0.38		46123.73	22921.82
6	938.3	4828.0	12	0.68	0.42		19110.31	21875.58
7	1063.7	4777.9	12	0.61	0.39		25702.94	24784.82
8	1209.2	4741.5	12	0.68	0.42		25170.31	24481.35

By these calculations, the system capability is 18512.13 lb, which is 2.03 times the payload that is found by assuming full suspension.

Discussion

The major difference between determining payload capability by this method and traditional methods is the calculation of the load factors. This also is the most time-consuming part of the procedure. The procedure can be simplified significantly by using one or more "average" load factors calculated on the basis of one or more "average" ground slopes. The results will still reflect the effects of partial suspension without much more effort than traditional methods.

Running Skyline

A typical running skyline (Fig. 7) has one line that serves both as a skyline and a haulback line. This line is usually called the haulback line.

Cable Geometry

Since the length of the haulback line varies as the turn is moved toward the landing, the load clearance (h_L) is considered to be constant for determination of payload capability. The path of the carriage under these conditions is also shown in Figure 5. The cable geometry is then described by first specifying the coordinates and heights of the yarder spar and tailhold, and then specifying each load point in terms of its coordinates and the constant load clearance.

Log Geometry

Since the load clearance remains constant, the carriage clearance, y_c , does too. For running skyline carriages, it is assumed that $y_c = h_L$ without significant error. Therefore, the only log geometry parameter that will change significantly from one load point to another is the ground slope.

Procedure

The assumption that the carriage clearance is constant makes the procedure for determining payload capability for a running skyline essentially the same as for the live skyline. The inputs are only slightly different. Two main steps are:

1. Use the "Partial Suspension Load Factors" program (Appendix 2) to determine the partial suspension load factors for each terrain point for which capability is to be determined.
2. Use the "Partial Suspension Payload (III)" program (Appendix 3) to determine the allowable payloads for each terrain point for which capability is to be determined.

The least of these payloads is the one taken to be the maximum load that the system can carry without exceeding any of the allowable tensions.

Example

The profile data of Figure 6A and the data that follow illustrate the procedure.

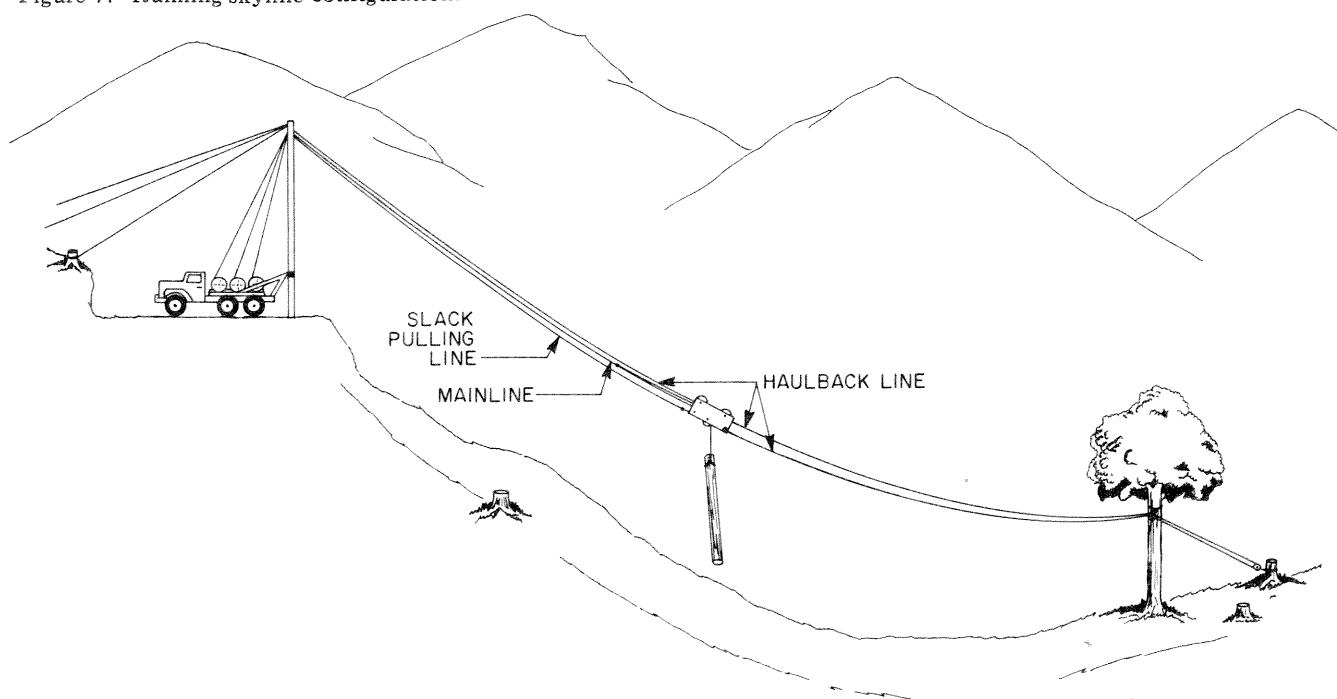
$$\begin{array}{lll} \omega_1 = 1.85 \text{ lb/ft} & T_1 = 34500 \text{ lb} & \mu = 0.60 \\ \omega_3 = 3.70 \text{ lb/ft} & T_3 = 34500 \text{ lb} & l_c = 40' \\ W_c = 750 \text{ lb} & & l_c = 16' \end{array}$$

Yarder location: T.P. 3, $h_Y = 50'$

Tailhold location: T.P. 10, $h_T = 20'$

Load clearance: $h_L = 12'$

Figure 7.—Running skyline configuration.



Step 1. Use the "Partial Suspension Load Factor" program (Appendix 2) to determine the load factors.

1. Input $\mu = 0.60$ (Key A)
2. Input $l_q = 40$ and $l_c = 16$ (Key B)
3. For each terrain point, enter the ground slope (Key C), and then enter the carriage clearance (Key D). the values of v and h will be displayed. The result is:

Terrain point	Input		Output	
	θ	Y_c	v	h
4	0.40	12	0.68	0.42
5	0.20	12	0.58	0.38
6	0.40	12	0.68	0.42
7	0.25	12	0.61	0.39
8	0.40	12	0.68	0.42

Step 2. Use the "Partial Suspension Payload (III) program (Appendix 3) to determine the payload capability.

1. Input $T_3 = 34500$
 $\omega_3 = 3.70$
 $T_4 = 1$ and $\omega_4 = 1$ (Key A)
2. Input $f = 2$
 $W_c = 750$
 $T_1 = 34500$ and $\omega_1 = 1.85$ (Key B)
3. Input $X_Y = 568.0$
 $Y_Y = 4968.2$
 $h_Y = 50$ (Key fA)
4. Input $X_T = 1459.9$
 $Y_T = 4737.8$
 $h_T = 20$ (Key fB)
5. For each terrain point, enter the load point coordinates and the load clearance (Key fC), and then enter the load factors, v and h , and calculate the payload based on allowable haulback tension (Key E). Use Key fE to calculate the payload based on allowable mainline tension. The results are:

Terrain point	Inputs					Outputs	
	X_L	Y_L	h_L	v	h	$W_n(T_1)$	$W_n(T_3)$
4	675.2	4903.9	12	0.68	0.42	171092.93	36228.59
5	791.2	4857.5	12	0.58	0.38	94372.44	34848.72
6	938.3	4828.0	12	0.68	0.42	39639.30	22110.78
7	1063.7	4777.9	12	0.61	0.39	52884.97	27364.27
8	1209.2	4741.5	12	0.68	0.42	51535.80	26801.60

On the basis of these results, the net allowable system payload is 22110.78 lb and is mainline limited. This payload is 1.40 times the payload determined with a full suspension analysis.

Discussion

There is essentially no difference in procedure for payload determinations for the running skyline and live skyline except for the inputs on one of the programs. Different input is needed because different forces act at the carriage for a running skyline and a live skyline.

The major difference between determining payload capability by this method and traditional methods is the calculation of the load factors. This also is the most time-consuming part of the procedure. The procedure can be simplified significantly by using one or more "average" ground slopes.

The amount of accuracy sacrificed depends on the variation in ground slope. However, the results will still reflect the effects of partial suspension without much more efforts than traditional methods.

Note that some running skylines, because they operate on an essentially constant haulback tension regardless of load, deviate from the conditions described. The constant haulback tension causes a cable geometry with a varying, rather than a constant, load clearance. However, the maximum payload for these conditions can be calculated in the way described without a significant decrease in accuracy.

Standing Skyline

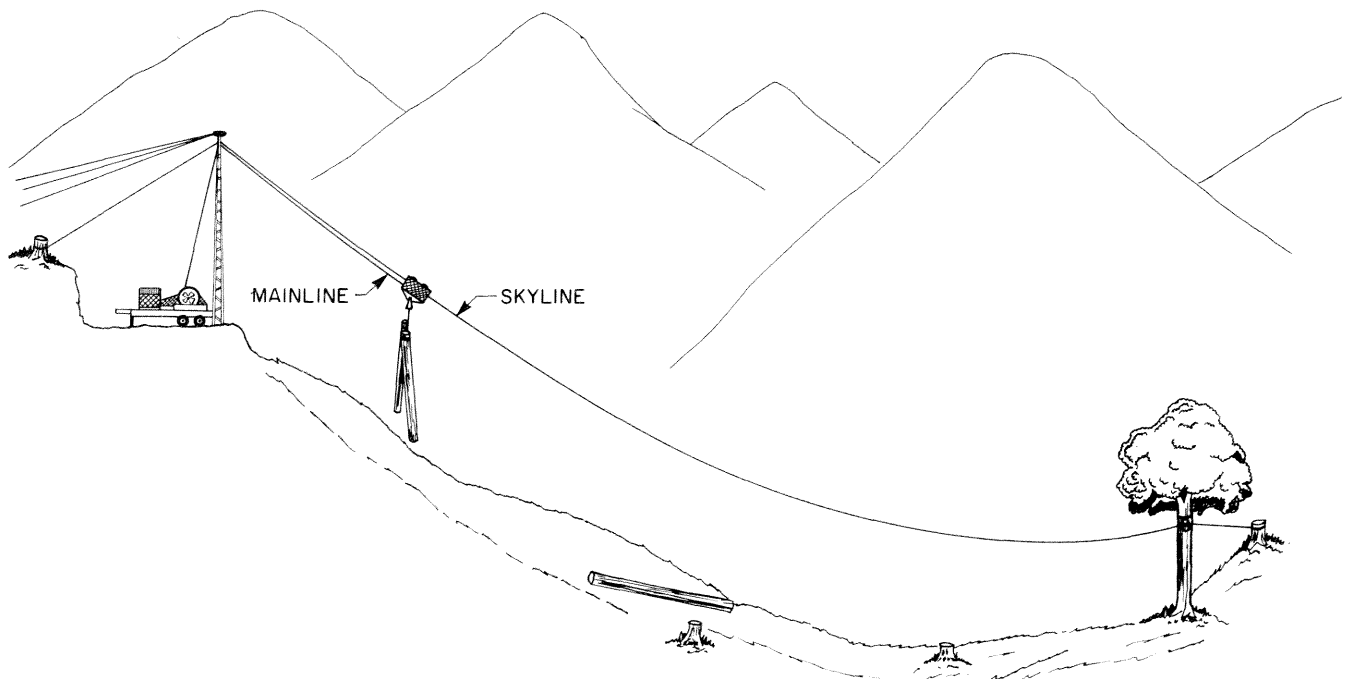
A typical standing skyline configuration is shown in Figure 8. If the skyline length is not varied as the carriage is moved along it, the system is analyzed as a standing skyline. This distinction is important because it determines the cable geometry.

Cable Geometry

Since the skyline is essentially constant, the path that the carriage takes is elliptical (Fig. 9). This path can be described mathematically once the skyline length is known. Hence, the system geometry can be determined.

Figure 10 illustrates that for each point on a given profile there is an associated skyline length (L_s) that allows passage

Figure 8.—Standing skyline configuration.



of the carriage at *exactly* the required clearance. Since these lengths vary, as illustrated, there is only one length that will allow the carriage to pass each terrain point *within* the allowable clearance, which is obviously the shortest of all possible lengths. The shortest skyline length is found by calculating the length required to pass the carriage at exactly the required clearance for several terrain points until it is certain that a shortest one has been found. By using the shortest skyline length, S_o , the system geometry is specified by finding the deflection, y , at any distance, d , with the mathematical expression describing the elliptical load path.

Log geometry

Because of the elliptical load path, the load clearance, h_L , and the carriage clearance, y_c , vary as the carriage moves

along the skyline. This means that the amount of suspension can vary considerably for a standing skyline, and the load factors can vary considerably also.

Procedure

Payload capability analysis of the standing skyline is more involved than the live or running skyline systems because of the fixed skyline length. The three primary steps are:

1. Use the "Standing Skyline Length and Load Path" program (Appendix 1) to determine the skyline length, $\bar{S}_o$, then determine the cable geometry parameters, L and E , for the system, and then determine the geometry parameters d , y , and y_c for each load point.
2. Use the "Partial Suspension Load Factors" program (Appendix 2) to determine the partial suspension load factors for each load point.

Figure 9.—Elliptical load path of a standing skyline.

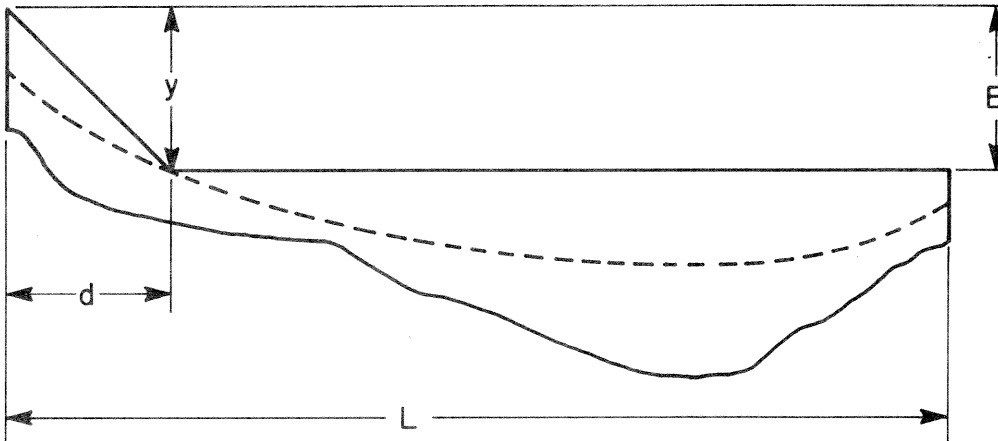
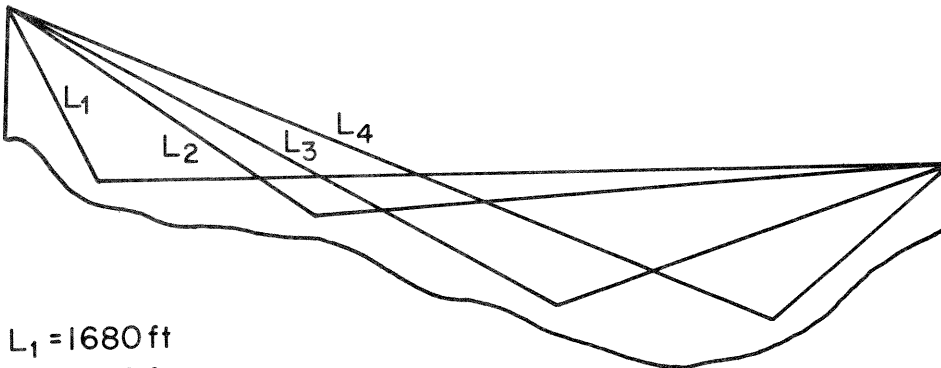


Figure 10.—Skyline lengths.



$L_1 = 1680 \text{ ft}$
 $L_2 = 1020 \text{ ft}$
 $L_3 = 1680 \text{ ft}$
 $L_4 = 1620 \text{ ft}$

3. Use the “Partial Suspension Payload (III)” program (Appendix 3) to determine the allowable payloads.

The least of the payloads is the one taken to be the maximum load the system can support without exceeding any of the allowable tensions.

Example

The profile data of Figure 6A and the data that follow illustrate the procedure.

$$\begin{aligned}\omega_1 &= 1.85 \text{ lb/ft} & T_1 &= 34500 \text{ lb} & \mu &= 0.60 \\ \omega_3 &= 0.72 \text{ lb/ft} & T_3 &= 13700 \text{ lb} & 1_\ell &= 40 \text{ ft} \\ \omega_4 &= 0.46 \text{ lb/ft} & T_4 &= 8900 \text{ lb} & 1_c &= 16 \text{ ft} \\ W_c &= 750 \text{ lb}\end{aligned}$$

Yarder location: T.P. 3, $h_Y = 50$ ft

Tailhold location: T.P. 10, $h_T = 20$ ft

Load clearance: $h_L = 12$ ft

Step 1. Use the “Standing Skyline—Length and Load Path” program (Appendix 1) to determine the skyline length, $\bar{S}_O$, the cable geometry parameters, L and E, for the system, and then cable geometry parameters, d and y, and the carriage clearance, y_c , for each load point.

1. Input $X_Y = 568.0$
 $X_Y = 4968.2$ (Key fA)
2. Input $X_T = 1459.9$
 $Y_T = 4737.8$ (Key fB)
3. Input $h_Y = 50$
 $h_T = 0$
 $h_L = 12$ (Key fD)
4. For each terrain point that seems as if it might limit the skyline length, enter the coordinates (Key fC) and then calculate the length, L_s , and the distance, d. The results are:

Terrain point	Inputs		Outputs	
	X_T	Y_L	L_S	d
5	791.2	4857.5	946.16	223.2
6	938.3	4828.0	938.98	370.3
7	1063.7	4777.9	943.24	495.7
8	1209.2	4741.5	944.43	641.2
9	1339.2	4689.5	966.88	771.2

The limiting skyline length, $\bar{S}_O$, according to these calculations is $\bar{S}_O = 938.98$

5. Determine the cable geometry parameters, L and E, for the system (Key E).

These are $L = 891.9$ ft, and $E = 260.4$ ft.

6. Input $\bar{S}_O = 938.98$ (Key A) then determine the cable geometry parameters, d and y, and the carriage clearance, y_c , for each load point. The results are:

Terrain point	Input	Output	Input	Output
	d	y	Y_L	y_c
4	107.2	80.13	4903.9	34.17
5	223.2	128.00	4857.5	32.70
6	370.3	178.18	4828.0	12.02
7	495.7	214.54	4777.9	25.76
8	641.2	249.54	4741.5	27.16
9	771.2	271.91	4689.5	56.79

Step 2. Use the “Partial Suspension Load Factors” program (Appendix 2) to determine the load factors for each load point.

1. Input $\mu = 0.60$ (Key A)
2. Input $1_\ell = 40$ and
 $1_c = 16$ (Key B)
3. For each load point enter the ground slope (Key C) and then the carriage clearance (Key D). The calculator will display the load factors. The results are:

Terrain point	Input		Output	
	θ	Y_c	v	h
4	0.40	34.17	0.81	0.25
5	0.20	32.70	0.71	0.26
6	0.40	12.02	0.68	0.41
7	0.25	25.76	0.69	0.31
8	0.40	27.16	0.77	0.30
9	-0.40	56.79	0.57	0.07

Step 3. Use the “Partial Suspension Payload (III)” program (Appendix 3) to determine the payloads based on the appropriate line tensions.

1. Input $T_3 = 13700$
 $\omega_3 = 0.72$
 $T_4 = 8900$ and
 $\omega_4 = 0.46$ (Key A)
2. Input $f = 1$
 $W_c = 750$
 $T_1 = 34500$
 $\omega_1 = 1.85$ (Key B)
3. Input $L = 891.9$ and
 $E = 260.4$ (Key C)
4. For each load point enter d and y (Key D), and then enter v and h and calculate $W_n(T_1)$ (Key E). Calculate $W_n(T_3)$ (Key fE). The results are:

Terrain point	Inputs				Outputs	
	<i>d</i>	<i>y</i>	<i>v</i>	<i>h</i>	$W_n(T_1)$	$W_n(T_3)$
4	107.2	80.13	0.81	0.25	24998.71	22788.37
5	223.2	128.00	0.71	0.26	19363.69	26596.51
6	370.3	178.18	0.68	0.41	18912.37	22226.53
7	495.7	214.54	0.69	0.31	16039.00	27718.86
8	641.2	249.54	0.77	0.30	15145.13	29472.18
9	771.2	271.91	0.57	0.07	24305.71	98099.36

On the basis of these results, the limiting payload is 15145.13 lb which is 1.70 times the payload determined with a full suspension analysis.

Discussion

The analysis of a standing skyline is more complex than the analysis of the live or running skyline, because Step 1 must be used to determine skyline length and load path. The remaining two steps are identical, as far as the mechanics are concerned.

Traditionally, the only load point that is examined for a standing skyline analysis is at midspan. However, the determination of the cable geometry and load factors can be critical because the payload capability at any load point is as sensitive to the amount of suspension as it is to the amount of deflection, and because the amount of suspension can vary from full suspension to no suspension quite easily, depending on the topography, there is no assurance that the limiting load will be at midspan. Therefore, the payload for several terrain points should be determined to be certain which one limits the capability of the system. Payload predictions, based on the payload at midspan only, can easily be 50 percent off, and it is not unusual for them to be 80 percent off.

For typical yarders with typical line sizes, a live skyline analysis will nearly always yield a payload capability at least as large as a standing skyline analysis will yield. Therefore, it may be convenient to analyze a profile for a live skyline first. If a satisfactory payload capability is not obtained, there is no point in analyzing the profile for a standing skyline. As experience is gained in using the programs, it will be easier to identify the "critical" terrain points as well as to estimate how much less a standing skyline will carry than that of a live skyline on a given profile.

Variations in Yarding Conditions

The programs used in these analyses are based on the assumption that the yarder is higher in elevation than the tailhold and that the logs moved toward the yarder. However, variations in yarding circumstances can and do occur. For example, it may be desirable to move the log away from the yarder, and some systems are designed with the yarder lower in elevation than the tailhold. The programs can be used to

predict payloads for each of these variations if the proper inputs are made.

Yarder Position

If the top of the yarder spar is higher than the top of the tailhold (elevation difference, $E > 0$), then no modifications for yarder position are required. If the reverse is true ($E < 0$), then the allowable tensions should be reduced because the tension in any cable (for a given load at a given location) is maximum at its highest point in the system. The algorithms in the programs use the tensions at the yarder spar because that is assumed to be the highest point. If the yarder is lower than the tailhold, the maximum skyline and haulback tensions are at the tailhold. To account for this, the allowable tensions should be reduced by the product of the line's weight and the elevation difference between the top of the yarder spar and the top of the tailhold. The relationship is expressed by equation 2.

$$T'_{all} = T_{all} + \omega E \quad (2)$$

where

T'_{all} = allowable tension with yarder lower than tailhold

T_{all} = allowable tension with yarder higher than tailhold

ω = cable weight/foot

E = elevation difference, feet

Since the elevation difference, E , is negative when the yarder is lower than the tailhold, the allowable tensions will be reduced accordingly. The tensions in all lines should be reduced, even though that may yield results that could be slightly conservative if the payload is limited by mainline tension.

Direction of Movement

The direction of log movement, whether toward or away from the yarder, is another variation that may require modification to the inputs. Consider the free body diagram of Figure 3. In particular note that the horizontal component of force due to drag resistance, the " hW_n " force, is toward the right. This is true if the turn is to be moved toward the yarder which is assumed to be on the left. But, if the turn is to be moved away from the yarder, this " hW_n " force would be toward the left. This discrepancy is corrected by simply reversing the sign of the horizontal load factor, h . The load factors are calculated first as they would be normally (give careful attention to which ground slope is specified as well as the sign of the ground slope); then the sign of the horizontal factor, h , is reversed only if the load is to be moved away from the yarder.

The modifications are simple, but because they are sometimes contrary to traditional thinking, they can be confusing.

For this reason, the following chart summarizes the required modifications and the following examples illustrate them:

Yarder position	Log movement	
	Toward yarder	Away from yarder
Above (Elevation difference $E > 0$)	No modifications	Reverse sign of h
Below (Elevation difference $E < 0$)	Reduce tensions	Reduce tensions Reverse sign of h

Example

To illustrate the modifications for the variations in yarding conditions, consider the profile data of Figure 6A and 6B, both of which are in standard form for having the yarder on the left. These profiles are the same; one is merely the reverse of the other. Note that the beginning coordinates are completely arbitrary. In addition, consider that a live skyline will be used with the same specifications as listed on page 4. It should also be noted that the modifications are the same for running and standing skylines.

Yarder position above. With the yarder at T.P. 3 and the tailhold at T.P. 10, use the profile data of Figure 6A. If the logs were to be moved toward T.P. 3, no modifications would be required to the inputs.

If however, the turns were brought toward T.P. 10 (away from the yarder), the load factors will be different, because a different ground slope is specified. Then the sign of each factor, h , will need to be reversed after it has been calculated. The change in sign of h is the only modification required. The results are:

Terrain Point	Inputs			Outputs		
	θ	v	h	$W_n(T_1)$	$W_n(T_3)$	$W_n(T_4)$
4	-0.60	0.50	0.00	47049.33	54360.12	
5	-0.40	0.06	-0.15	146881.20		76540.88
6	-0.20	0.21	-0.28	32554.14		43902.03
7	-0.40	0.06	-0.15	140074.39		68191.04
8	-0.25	0.16	-0.25	76634.69		40343.56
9	-0.40	0.06	-0.15	-2616210.54		52915.55

These results show that the system can carry a load of 32554.14 lb without exceeding the allowable tensions. This is 3.56 times the payload determined by full suspension analysis. Note that the system is haulback limited.

Yarder position below. If the yarder is at T.P. 10 and the tailtree at T.P. 3, then the profile would be specified as shown in Figure 6B, to be in standard form. Because the yarder is lower than the tailhold ($E < 0$), the allowable tensions should be reduced by the product of the cable's weight and the elevation difference, E . In this case, $E = -200.40$ ft and the appropriate reductions are:

$$T_1 = 34500 - (200.40)(1.85) = 34100 \text{ lb}$$

$$T_3 = 13700 - (200.40)(0.72) = 13600 \text{ lb}$$

$$T_4 = 8900 - (200.40)(0.46) = 8800 \text{ lb}$$

These reduced tensions are entered as the allowable tensions, and the payloads are determined as before. If the turns were to be brought toward the yarder, the load factors would be calculated normally and *not* reversed. The results for the load factors and payloads are:

Terrain point	Load factors			Payloads		
	θ	v	h	$W_n(T_1)$	$W_n(T_3)$	$W_n(T_4)$
8	-0.25	0.16	0.25	115008.09	57190.17	
7	-0.40	0.06	0.15	177866.34	99644.09	
6	-0.20	0.21	0.28	32662.72	61888.79	
5	-0.40	0.06	0.15	135191.48	110001.99	
4	-0.60	0.50	0.00	31247.58		44503.18

These results show that a payload of 31247.58 lb is possible without exceeding the allowable tensions. This is 3.68 times the payload determined with a full suspension analysis.

If the log was moved away from the yarder, then the load factors will be different, because of the difference in specified ground slope. In addition, the sign of the load factor, h , would need to be reversed. The results for both the load factors and payloads are:

Terrain point	Load factors			Payloads		
	θ	v	h	$W_n(T_1)$	$W_n(T_3)$	$W_n(T_4)$
8	0.40	0.68	-0.42	28886.70		17391.20
7	0.25	0.61	-0.39	25834.83		17077.77
6	0.40	0.68	-0.42	16608.61		15013.76
5	0.20	0.58	-0.38	32395.41		15718.12
4	0.40	0.68	-0.42	39380.92		13002.63

These results indicate that a payload capability of 13002.63 lb. can be expected, which is 1.53 times the payload found with a full suspension analysis.

Literature Cited

Binkley, Virgil W., and John Sessions.

(n.d.). **Chain and board handbook for skyline tension and deflection.** USDA For. Serv., Pac. Northwest Reg. Portland, Oreg., 191 p.

Carson, Ward W.

1975. **Analysis of running skyline with drag.** USDA For. Serv. Res. Pap. PNW-193. 8 p.

Carson, Ward W.

1976. **Determination of skyline load capability with a programmable pocket calculator.** USDA For. Serv. Res. Pap. PNW-205. 11 p.

Lysons, Hilton H., and Charles N. Mann.

1967. **Skyline tension and deflection handbook.** USDA For. Serv. Res. Pap. PNW-39. 41 p.

Program Description

Program Title Standing Skyline--Length and Load Path

Contributor's Name Gary D. Falk

Date: Sept. 1979

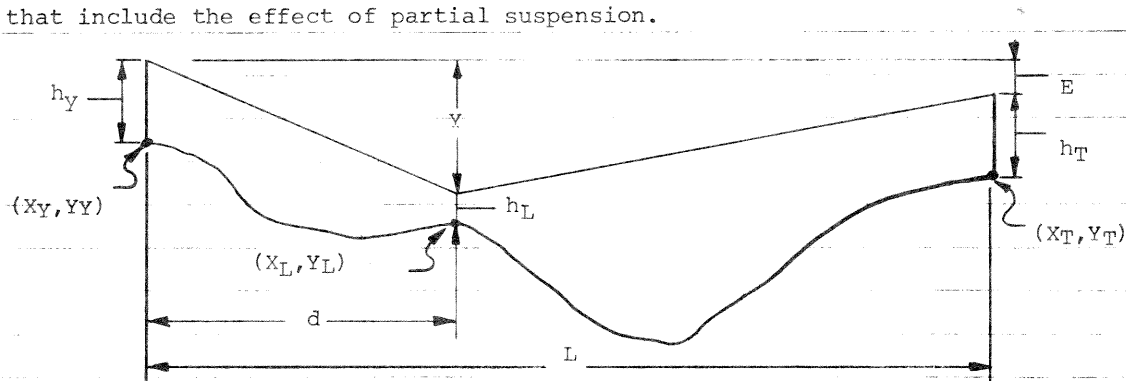
Address Forest Engineering Research, NE

City Morgantown

State West Virginia

Zip Code 26505

Program Description, Equations, Variables : This program is used for the determination of the cable geometry parameters necessary for a standing skyline payload analysis. It is basically the elliptical load path program developed by Ward Carson modified to use inputs more consistent with field data, to calculate a skyline length without the use of a secondary program, and to provide outputs that allow for payload analyses that include the effect of partial suspension.



X_Y, Y_Y = X and Y coordinates of yarder (ft)

X_T, Y_T = X and Y coordinates of tailhold (ft)

X_L, Y_L = X and Y coordinates of load point (ft)

h_Y, h_T, h_L = heights of yarder, tailhold, and load clearance at load point (ft)

Operating Limits and Warnings

Program Description

Program Title Standing Skyline--Length and Load Path (Con't)

Contributor's Name

Address

City

State

Zip Code

Program Description, Equations, Variables :

L_S = skyline length with h_L as load clearance (ft)

d = horizontal distance, yarder to load point (ft)

$\bar{S}_O$ = critical skyline length (Stretched, shortest of all L_S 's) (ft)

y = vertical distance, top of yarder spar to load point (ft)

y_C = load clearance with $\bar{S}_O$ as skyline length (ft)

w_1 = skyline weight (lb/ft)

T_1 = skyline allowable tension (lb)

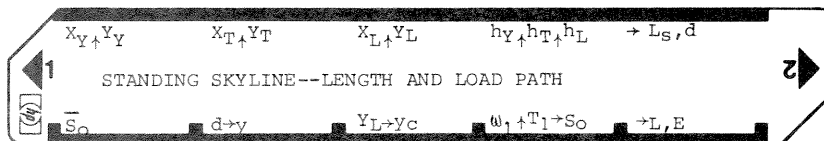
S_O = unstretched skyline length (ft)

L = horizontal distance, yarder to tailhold (ft)

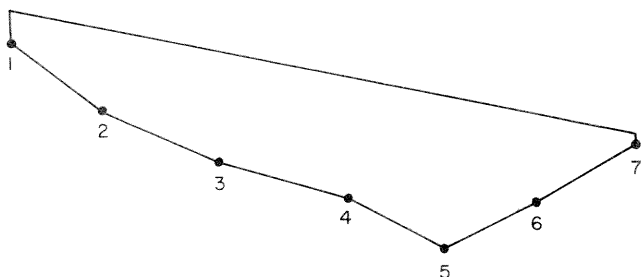
E = vertical distance, top of yarder spar to top of tailhold (ft)

Operating Limits and Warnings

User Instructions

[illegible]

The program is illustrated by determining the geometry parameters for a standing skyline for the following profile: a 55-foot yarder spar at T.P. 1, a 10-foot tailtree at T.P. 7, and a 12-foot minimum load clearance.



Terrain point	X Coord	Y Coord
1	0.00	5000.00
2	156.20	4875.10
3	357.40	4774.40
4	587.30	4705.50
5	753.80	4613.90
6	917.90	4687.80
7	1093.20	4784.20

The first step is to determine L_s for each load point that may limit the skyline length. Terrain points 2 to 6, inclusive will be examined to illustrate the procedure.

Key in $X_Y = 0.0$ and Enter ↑
Key in $Y_Y = 5000.0$ and fA
Key in $X_T = 1093.2$ and Enter ↑
Key in $Y_T = 4784.2$ and fB
Key in $X_L = 156.2$ and Enter ↑
Key in $Y_L = 4875.1$ and fC
Key in $h_Y = 55$ and Enter ↑
Key in $h_T = 10$ and Enter ↑
Key in $h_L = 12$ and fD
Key fE. The calculator should flash $L_s = 1170.92$, and then display $d = 156.20$. These are the values at T.P. 2 since the input values of X_L and Y_L were for that terrain point.

The values of L_s and d are found for the remaining terrain points by inputting X_L and Y_L for each terrain point (Key fC) and calculating the desired parameters (Key fE) as follows:

Key $X_L = 357.4$ and Enter ↑
Key $Y_L = 4774.4$ and fC
Key fE. The calculator should flash $L_s = 1182.92$, and then display $d = 357.40$. These are the values for T.P. 3.

The procedure is repeated for each terrain point that may limit the skyline length. The values for the remaining terrain points, along with the appropriate inputs, are:

Terrain point	Inputs		Outputs	
	X_L	Y_L	L_s	d
2	156.20	4875.10	1170.92	156.20
3	357.40	4774.40	1182.92	357.40
4	587.30	4705.50	1189.05	587.30
5	753.80	4613.90	1246.21	753.80
6	917.90	4687.80	1183.33	917.90

Since the shortest L_s is 1170.92, input that value as $\bar{S}_o$.

After it is input calculate the cable geometry.

Key in $\bar{S}_o = 1170.92$ and A.

Key in $d = 156.20$ and B. The calculator should display $y = 167.91$.

Key in $Y_Y = 4875.10$ and C. The calculator should display $Y_c = 11.99$. These are the values of y and Y_c for T.P. 2 since the input values of d and Y_Y were the values for the terrain point. Note that the actual clearance should have been 12.00. The difference is a result of rounding error.

The values of y and y_c are found for the remaining terrain points by inputting d and calculating y (Key B) and then inputting Y_L and calculating y_c (Key C) as follows:

Key $d = 357.40$ and B. The calculator should display $y = 247.99$.

Key $Y_L = 4774.40$ and C. The calculator should display $y_c = 32.61$. These are the values for T.P. 3. Note: If the distance parameter, d , was not determined previously, it can be determined manually by $d = X_L - X_Y$. It will then be in the X register ready to be input (Key B) as above.

The procedure is repeated for each terrain point for which payload capability is to be determined. The values for the remaining terrain points, along with the appropriate inputs, are:

Terrain point	d	Y	Y_L	Y_c
2	156.20	167.91	4875.10	11.99
3	357.40	247.99	4774.40	32.61
4	587.30	307.39	4705.50	42.11
5	753.80	332.75	4613.90	108.35
6	917.90	339.62	4687.80	27.58

In addition to determining the cable geometry parameters above, the distance and height parameter, L and E , can also be determined any time after the first trial L_s value has been determined. This is done by keying Key E.

Key E. The calculator should first flash $L = 1093.20$ and then display $E = 260.80$.

Also, it may be desired to know the unstretched skyline length, S_o , given the allowable tension and line weight. If the allowable tension (T_1) is 34500 lb and the weight (ω_1) is 1.85, then S_o is found as follows:

Key $\omega_1 = 1.85$ and Enter $\uparrow$
 Key $T_1 = 34500$ and D. The calculator should display $S_o = 1164.76$.

Appendix 2 Partial Suspension Load Factors

Program Description

Program Title Partial Suspension Load Factors

Contributor's Name Gary D. Falk

Date: Sept. 1979

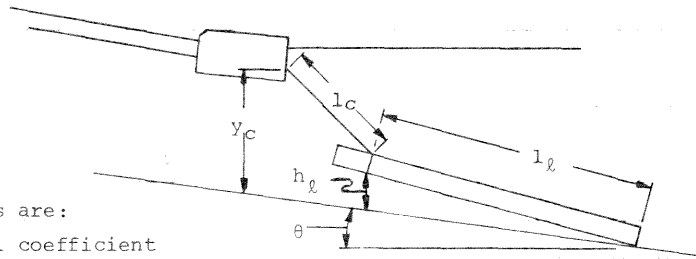
Address Forest Engineering Research, NE

City Morgantown

State West Virginia

Zip Code 26505

Program Description, Equations, Variables : This program is used to determine the amount of log payload that is carried by the carriage as vertical and horizontal force components. Its use is preliminary to skyline payload analyses that consider the effects of partial suspension. It may also be used to determine the required carriage-to-ground clearance for a specified log-to-ground clearance.



The parameters are:

μ = frictional coefficient

l_l = log length (ft) - measured from choker to end of log

l_c = choker length (ft) excluding amount to go around log

θ = ground slope (decimal) - positive if movement is uphill, negative if downhill.

y_c = carriage clearance (ft)

h_l = vertical log-to-ground clearance (ft)

v = ratio of vertical force at carriage to log weight

h = ratio of horizontal force at carriage to log weight

Operating Limits and Warnings

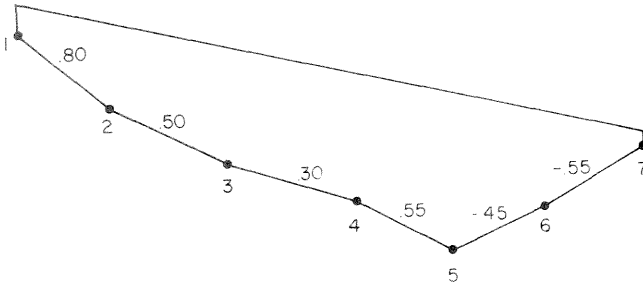
User Instructions

1 PARTIAL SUSPENSION LOAD FACTORS $\rightarrow v, h$

$\mu \uparrow$ $l \uparrow l_c$ $\Theta \uparrow$ $y_c \rightarrow v, h$ $h \rightarrow y_c, v, h$

[illegible]

The program is illustrated by finding the partial suspension load factors for terrain points 2 to 6, inclusive, of the following profile: friction coefficient, $\mu = 0.60$, log length, $l_l = 33$ ft, and a choker length, $l_c = 12$ ft.



Terrain point	θ	y_c
2	0.50	11.99
3	0.30	32.61
4	0.55	42.11
5	-0.45	108.35
6	-0.55	27.58

It should be emphasized that the ground slope to be specified for a particular load point is in the direction opposite that in which the log turn is to be moved. Also, the ground slope is positive if it is moved uphill, negative if it is moved downhill. For example, if T.P. 3 is to be examined, a ground slope of +0.30 should be specified if the turn is brought toward T.P. 1. However, a ground slope of -0.50 would be specified if the turn is brought toward T.P. 7.

The first step is to input the parameters that are common to all terrain points as follows:

Key in $\mu = 0.60$ and A

Key in $l_l = 33$ and Enter $\uparrow$

Key in $l_c = 12$ and B. The calculator is now ready to calculate the load factors.

T.P. 2 is the first to be examined. The inputs which follow are for that terrain point.

Key in $\theta = 0.50$ and C.

Key in $y_c = 11.99$ and D. The calculator should flash $v = 0.75$ and then display $h = 0.39$. The iterative routine used to calculate v and h will normally take about 1 minute to complete. It may be somewhat shorter or longer depending on the inputs.

The load factors for each successive terrain point is calculated by inputting θ (Key C) and then inputting y_c and calculating the load factors (Key D) as follows:

Key in $\theta = 0.30$ and C.

Key in $y_c = 32.61$ and D. The calculator should flash $v = 0.81$ and then display $h = 0.21$. These are the factors for T.P. 3.

The procedure is repeated for each load point for which the load factors are to be determined. The load factors for the remaining terrain points, along with the appropriate inputs, are given below:

Terrain point	Inputs		Outputs	
	θ	y_c	v	h
2	0.50	11.99	0.75	0.39
3	0.30	32.61	0.81	0.21
4	0.55	42.11	0.97	0.06
5	-0.45	108.35	1.00	0.00
6	-0.55	27.58	0.50	0.02

It is desirable to view the load factors again without spending the time necessary to recalculate them, simply Key fE, and the calculator will redisplay them.

Key fE. The calculator should first flash $v = 0.50$ and then display $h = 0.02$. These are the load factors for T.P. 6, which is the last terrain point examined.

This program also calculates the required carriage clearance for any combination of log and choker lengths, ground slopes, friction coefficients, and log-to-ground clearance. For example, to determine what carriage clearance is required to achieve a log-to-ground clearance of 1.5 ft for a log 40 ft long with a choker 16 ft long on a 25 percent ground slope, with a friction coefficient of 0.60--

Key in $\mu = 0.60$ and A

Key in $l_l = 40$ and Enter $\uparrow$

Key in $l_c = 16$ and B

Key in $\theta = 0.25$ and C.

Key in $h_1 = 1.5$ and E. The calculator should flash $y_c = 12.87$ and then flash $v = 0.61$ and then display $h = 0.39$.

For a ground slope of 50 percent

Key in $\theta = 0.50$ and C.

Key in $h_1 = 1.5$ and E. The calculator should flash $y_c = 11.32$ and then flash $v = 0.73$ and then display $h = 0.42$.

It should be emphasized that h_1 is the vertical clearance to the ground, and that the sign convention for the ground slope is positive for a log moving uphill and negative for a log moving downhill.

For negative ground slopes that are larger in magnitude than the friction coefficient, negative values of h will result. If the friction coefficient is equal in magnitude to the negative slope, division by zero will be attempted and an error will

result. If the factors for a situation such as this are desired, enter a value of ground slope just slightly larger in magnitude than the friction coefficient and this will allow the load factors to be determined.

Appendix 3 Partial Suspension Payload III

Program Description

Program Title Partial Suspension Payload III

Contributor's Name Gary D. Falk **Date:** March 1980

Address Forest Engineering Research, NE

City Morgantown, **State** West Virginia **Zip Code** 26505

Program Description, Equations, Variables This program will analyze running, live, and standing skyline systems for maximum payload capability based on specified allowable line tensions. Also, because it includes the effects of either a mainline or haulback on live and standing skylines, the most commonly used systems can be analyzed with this one program including downhill yarding situations. Although it was primarily developed to include the effects of partial suspension directly, full suspension analyses can be done with it.

The input parameters are described as follows: (See accompanying figure)

T_3 = allowable mainline tension at yarder

ω_3 = mainline weight per unit length
(mainline + slackpulling line weight for running skylines)

T_4 = allowable haulback tension (live and standing skylines)

ω_4 = haulback weight per unit length (live and standing skylines)

f = 1 for live and standing skylines
2 for running skylines

W_C = carriage weight

T_1 = allowable skyline tension at yarder
(haulback tension for running skylines)

ω_1 = skyline weight per unit length
(haulback weight for running skylines)

Operating Limits and Warnings The yarder is assumed to be on the left with increasing stationing to the right whether uphill or downhill yarding. Increased payloads by using both the mainline and haulback simultaneously is not considered. If either a mainline or a haulback is not used on the system being analyzed, "dummy" values should be input for the missing line or erroneous answers will result.

Program Description

Program Title Partial Suspension Payload III cont.

Contributor's Name _____

Address _____

City _____

State _____

Zip Code _____

Program Description, Equations, Variables

X_Y, Y_Y, h_Y = X and Y coordinates of yarder location and yarder spar height.

X_T, Y_T, h_T = X and Y coordinates of tailhold location and height.

X_L, Y_L, h_L = X and Y coordinates of load point and load clearance.

L = horizontal distance, yarder to tailhold

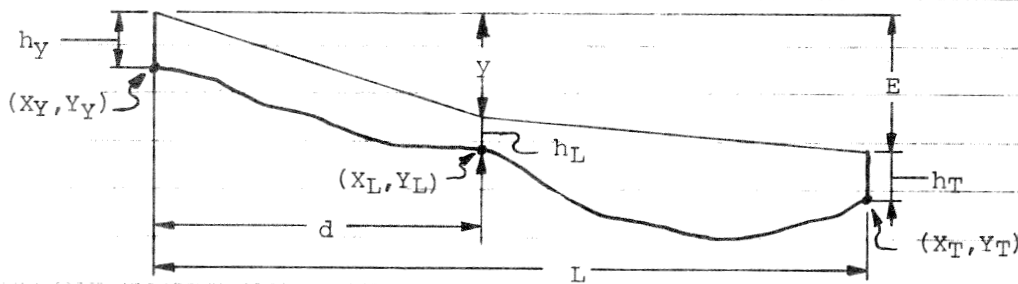
E = vertical distance, top of yarder to top of tailhold

d = horizontal distance, yarder to load point

y = vertical distance, top of yarder to load point

v = vertical partial suspension load factor

h = horizontal partial suspension load factor



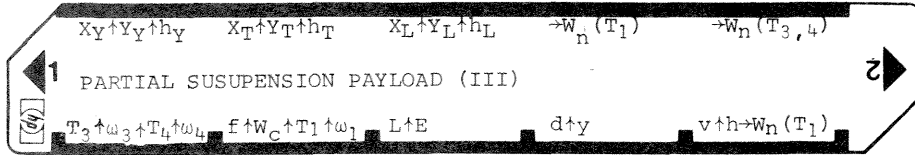
$W_n(T_1)$ = allowable payload based on specified tension in skyline. (haulback for running skyline)

$W_n(T_3)$ = allowable payload based on specified tension in mainline.

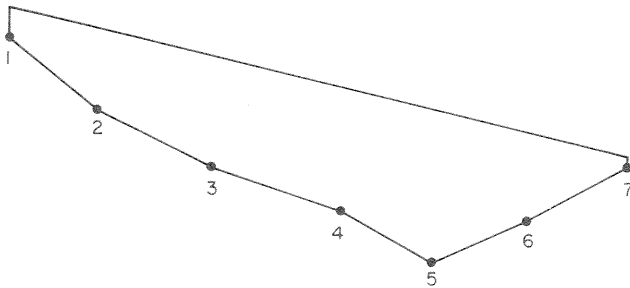
$W_n(T_4)$ = allowable payload based on specified tension in haulback. (inappropriate for running skyline)

Operating Limits and Warnings

User Instructions

[illegible]

The program is illustrated by calculating the payload capability for terrain points 2 to 6, inclusive, of the following profile for a running, live, and standing skyline. It should be mentioned that in order to illustrate the use of the program in a short example, the profile data used result in values that are somewhat atypical.



Terrain point	X Coord	Y Coord	v	h
1	0.00	5000.00		
2	156.20	4875.10	0.75	0.39
3	357.40	4774.40	0.66	0.38
4	587.30	4705.50	0.77	0.39
5	753.80	4613.90	0.09	0.11
6	917.90	4687.80	0.02	0.04
7	1093.20	4784.20		

Live Skyline

The following yarder specifications are given.

$T_3 = 13700$ lb	$f = 1$
$\omega_3 = 0.72$ lb/ft	$W_c = 700$ lb
$T_4 = \text{None}$	$T_1 = 34500$ lb
$\omega_4 = \text{None}$	$\omega_1 = 1.85$ lb/ft

Yarder location: T.P. 1, $h_y = 55$ ft

Tailhold location: T.P. 7, $h_T = 10$ ft

Minimum load clearance: $h_L = 12$ ft

Option 2 is normally the more efficient option to use for both the live and running skyline because it uses the reduced profile data directly. The first step is to input the yarder specifications, and use "dummy" values for the missing haulback line.

Key in $T_3 = 13700$ and Enter $\uparrow$
Key in $\omega_3 = 0.72$ and Enter $\uparrow$
Key in $T_4 = 1$ and Enter $\uparrow$
Key in $\omega_4 = 1$ and A
Key in $f = 1$ and Enter $\uparrow$
Key in $W_c = 700$ and Enter $\uparrow$
Key in $T_1 = 34500$ and Enter $\uparrow$
Key in $\omega_1 = 1.85$ and B.

The yarder and tailhold locations and heights are input after the yarder specifications.

Key in $X_Y = 0.0$ and Enter $\uparrow$
Key in $Y_Y = 5000.0$ and Enter $\uparrow$
Key in $h_Y = 55$ and fA
Key in $X_T = 1093.2$ and Enter $\uparrow$
Key in $Y_T = 4784.2$ and Enter $\uparrow$
Key in $h_T = 10$ and fB. The cable geometry parameters, L and E , are calculated and stored in the correct registers. They can be recalled from storage registers 1 and 2, respectively.

The calculator is now ready to begin to calculate the allowable payloads for each desired terrain point. T.P. 2 will be examined first. The inputs which follow are the values for that terrain point.

Key in $X_L = 156.2$ and Enter $\uparrow$

Key in $Y_L = 4875.1$ and Enter $\uparrow$

Key in $h_L = 12$ and fC

Key in $v = 0.75$ and Enter $\uparrow$

Key in $h = 0.39$ and E. The calculator should display $W_n(T_1) = 94433.08$

Key fE. The calculator should display $W_n(T_3) = 18108.71$. These are the maximum payloads at this point based on the allowable tensions in the respective cables.

The payloads for the remaining terrain points are calculated by inputting the X and Y coordinates of the load point and the load clearance (Key fC), then inputting the load factors and calculating $W_n(T_1)$ (Key E) (or Key fD, as illustrated later), and then calculating $W_n(T_3)$, (or $W_n(T_4)$, as shown later) (Key fE). This is shown for T.P. 3 as follows:

Key in $X_L = 357.4$ and Enter $\uparrow$

Key in $Y_L = 4774.4$ and Enter $\uparrow$

Key in $h_L = 12$ and fC

Key in $v = 0.66$ and Enter $\uparrow$

Key in $h = 0.38$ and E. The calculator should display $W_n(T_1) = 63994.12$.

Key fE. The calculator should display $W_n(T_3) = 22180.32$.

The procedure is repeated for each load point for which capability is to be determined. The values for the remaining terrain points, along with the appropriate inputs are shown as follows:

Terrain point	Inputs					Outputs	
	X_L	Y_L	h_L	v	h	$W_n(T_1)$	$W_n(T_3)$
2	156.20	4875.10	12	0.75	0.39	94433.08	18108.71
3	357.40	4774.40	12	0.66	0.38	63994.12	22180.32
4	587.30	4705.50	12	0.77	0.39	40912.28	24091.97
5	753.80	4613.80	12	0.09	0.11	1101109.95	106181.56
6	917.90	4687.80	12	0.02	0.04	5640766.73	321004.75

Running Skyline

The running skyline procedure is essentially the same as the live skyline procedure. The differences are in the yarder specification inputs and, of course, the outputs. The following yarder specifications are given:

$T_3 = 34500$ lb $f = 2$
 $\omega_3 = 3.70$ lb/ft $W_c = 700$ lb
 $T_4 = \text{None}$ $T_1 = 34500$ lb
 $\omega_4 = \text{None}$ $\omega_1 = 1.85$ lb/ft
 Yarder location: T.P. 1, $h_Y = 55$ ft
 Tailhold location: T.P. 7, $h_T = 10$ ft
 Minimum load clearance: $h_L = 12$ ft

As stated before, option 2 is the more efficient option to use for the running skyline. The first step is to input the yarder specifications, and be certain to input "dummy" values for the missing line.

Key in $T_3 = 34500$ and Enter $\uparrow$
 Key in $\omega_3 = 3.70$ and Enter $\uparrow$
 Key in $T_4 = 1$ and Enter $\uparrow$
 Key in $\omega_4 = 1$ and A
 Key in $f = 2$ and Enter $\uparrow$
 Key in $W_c = 700$ and Enter $\uparrow$
 Key in $T_1 = 34500$ and Enter $\uparrow$
 Key in $\omega_1 = 1.85$ and B.

The yarder and tailhold locations and heights are input after the yarder specifications.

Key in $X_Y = 0.0$ and Enter $\uparrow$
 Key in $Y_Y = 5000.0$ and Enter $\uparrow$
 Key in $h_Y = 55$ and fA
 Key in $X_T = 1093.2$ and Enter $\uparrow$
 Key in $Y_T = 4784.2$ and Enter $\uparrow$
 Key in $h_T = 10$ and fB. The cable geometry parameters, L and E, are calculated and stored in the correct registers. They may be viewed by recalling them from registers 1 and 2, respectively.

The calculator is now ready to begin to calculate the allowable payloads for each desired terrain point. T.P. 2 will be examined first. The inputs which follow are for that terrain point.

Key in $X_L = 156.2$ and Enter $\uparrow$
 Key in $Y_L = 4875.1$ and Enter $\uparrow$
 Key in $h_L = 12$ and fC.
 Key in $v = 0.75$ and Enter $\uparrow$
 Key and $h = 0.39$ and E. The calculator should display $W_n(T_1) = 190838.75$.

Key fE. The calculator should display $W_n(T_3) = 36370.36$. These are the maximum payloads at T.P.2 based on the allowable tensions in the respective cables.

The payloads for the remaining terrain points are calculated by inputting the X and Y coordinates of the load point and the load clearance (fC), then inputting the load factors and calculating $W_n(T_1)$ (Key E), and then calculating $W_n(T_3)$ (Key fE). This is shown for T.P. 3 as follows:

Key in $X_L = 357.4$ and Enter $\uparrow$
 Key in $Y_L = 4774.4$ and Enter $\uparrow$
 Key in $h_L = 12$ and fC.
 Key in $v = 0.66$ and Enter $\uparrow$
 Key in $h = 0.38$ and E. The calculator should display $W_n(T_1) = 129609.04$.

Key in fE. The calculator should display $W_n(T_3) = 37930.77$.

The procedure is repeated for each load point for which capability is to be determined. The values for the remaining terrain points, along with the appropriate inputs are shown as follows:

Terrain point	Inputs					Outputs	
	X_L	Y_L	h_L	v	h	$W_n(T_1)$	$W_n(T_3)$
2	156.20	4875.10	12	0.75	0.39	190838.75	36370.36
3	357.40	4774.40	12	0.66	0.38	129609.04	37930.77
4	587.30	4705.50	12	0.77	0.39	82847.26	33760.59
5	753.80	4613.90	12	0.09	0.11	2221119.44	227881.23
6	917.90	4687.80	12	0.02	0.04	11390764.75	713940.21

Standing Skyline

The same yarder specifications as those used for the live skyline example will be used for this example. In addition, a haulback line will be specified.

$T_3 = 13700$ lb $W_c = 700$ lb
 $\omega_3 = 0.72$ lb/ft $T_1 = 34500$ lb
 $T_4 = 8900$ lb $\omega_1 = 1.85$ lb/ft
 $\omega_4 = 0.46$ lb/ft
 Yarder location: T.P. 1, $h_Y = 55$ ft
 Tailhold location: T.P. 7, $h_T = 10$ ft

In addition to the above data, the following inputs will be used because they have been previously determined with the "Standing Skyline—Length and Load Path" and "Partial Suspension Load Factors" programs.

$L = 1093.20$ $E = 260.80$

<i>Terrain point</i>	<i>d</i>	<i>y</i>	<i>v</i>	<i>h</i>
2	156.20	167.91	0.75	0.39
3	357.40	247.99	0.81	0.21
4	587.30	307.39	0.97	0.06
5	753.80	332.75	1.00	0.00
6	917.90	339.62	0.50	0.02

Because the cable geometry parameters L, E, d, and y have been previously determined, option 1 is the more convenient option to use for the standing skyline. The first step is to input the yarder specifications.

Key in T_3 = 13700 and Enter ↑
 Key in ω_3 = 0.72 and Enter ↑
 Key in T_4 = 8900 and Enter ↑
 Key in ω_4 = 0.46 and A
 Key in f = 1 and Enter ↑
 Key in W_c = 700 and Enter ↑
 Key in T_1 = 34500 and Enter ↑
 Key in ω_1 = 1.85 and B.

The cable geometry parameters L and E are input next.

Key in L = 1093.20 and Enter ↑
 Key in E = 260.80 and C. The calculator is now ready to begin calculating payloads.

The payload at T.P. 6 is calculated first because it illustrates what happens when a haulback is required. The inputs which follow are the values for that terrain point.

Key in d = 917.90 and Enter ↑
 Key in y = 339.62 and D.
 Key in v = 0.50 and Enter ↑
 Key in h = 0.02 and E. The calculator should display $W_n(T_1)$ = 0.00. This means that a haulback is required at this load point to maintain carriage stability. To calculate $W_n(T_1)$:
 Key fD. The calculator should display $W_n(T_1)$ = 48028.95.
 Key fE. The calculator should display $W_n(T_4)$ = 3866150.98. It should be emphasized that the only time it is necessary to key fD to determine $W_n(T_1)$ is when the display from Key E is 0.00. The display from Key fE is $W_n(T_4)$ when the 0.00 is displayed.

The basis for using this procedure is that it is often difficult to determine whether a mainline or haulback is necessary, especially for "downhill" yarding under partial-suspension conditions. Payloads calculated by assuming that a mainline is used when a haulback is required are not valid and vice versa. This way the user not only has valid payloads, but also knows whether a mainline or haulback, or both, are required on a particular profile.

The payload for each load point for which capability is to be determined is found by inputting d and y (Key D), then inputting the load factors and calculating $W_n(T_1)$ (Key E) (or Key fd, as appropriate), and then calculating $W_n(T_3)$ or $W_n(T_4)$ (Key fE). This is shown for T.P. 5 as follows:

Key in d = 753.80 and Enter ↑

Key in y = 332.75 and D.

Key in v = 1.00 and Enter ↑

Key in h = 0.00 and E. The calculator should display $W_n(T_1)$ = 19625.06.

Key in fE. The calculator should display $W_n(T_3)$ = 131099.13.

The procedure is repeated for each load point for which capability is to be determined. The values for the remaining terrain points are shown below:

<i>Terrain point</i>	$W_n(T_1)$	$W_n(T_3)$ or $W_n(T_4)$
2	94447.92	18108.43
3	31722.79	28258.11
4	20031.90	52228.31
5	19625.06	131099.13
6	48028.95	3866150.98

In the previous examples it was assumed that the user started out without having previously input any of the parameters. If previous correct values were input, it is not necessary to re-enter them. This is particularly useful when going on to analyze another profile or changing the position of the yarder or tailhold or heights without changing yarder specifications. However, when at least one value, which is input with a particular key, is to be changed, all the values input with that key must be entered whether they change or not. For example, to increase the tailtree height to 20 feet without changing the location, it would be necessary to re-enter the location along with the changed height. If they aren't re-entered, erroneous values will be entered for its location. After changing any values, the load point (Key D or fC, whichever is appropriate) must be re-entered as well, even if it does not change. The load factors must always be input before Key E is used to calculate $W_n(T_1)$.

Note, also, that the inputs with Keys A and B can be made after the inputs with Keys fA and fB. This is so that E can be determined and adjustments made to the allowable tensions of the yarder when it is below the tailhold. All other inputs should be made in the specified order or erroneous answers will result.

Appendix 4 Equations

Cable Geometry

Live and running skyline. Given the coordinates and heights of the yarder, tailtree, and load point (Fig. 1) the cable geometry parameters L , E , d , and y are determined by the following equations:

$$L = (X_T - X_Y) \quad (1.1.0)$$

$$E = (Y_Y + h_Y) - (Y_T + h_T) \quad (1.2.0)$$

$$d = (X_T - X_L) \quad (1.3.0)$$

$$y = (Y_Y + h_Y) - (Y_L + h_L) \quad (1.4.0)$$

Standing skyline. The skyline length that allows passage of the carriage at exactly the required clearance at any trial load point is:

$$L_s = [(d)^2 + (y_t)^2]^{1/2} + [(L-d)^2 + (y_t - E)^2]^{1/2} \quad (1.5.0)$$

where L , E , d , and y_t are given by equation 1.1.0 through 1.4.0, respectively. The difference between y and y_t , which are both given by equation 1.4.0, is that y_t is only a "trial" value for a standing skyline. The actual value of y is determined after the limiting skyline length ($\bar{S}_o$) is determined.

The skyline length given by equation 1.5.0 is the sum of two straight line cable segments. The difference between this length and the more accurate catenary length is insignificant for cables tensioned to about one-third of their breaking strength. As a result of this simplifying assumption, the error is less than the error that is introduced as a result of temperature differentials.

The limiting skyline length, $\bar{S}_o$, is determined by using equation 1.5.0 to calculate L_s for several points, and the shortest of these is $\bar{S}_o$. After the limiting skyline length is determined the following system of equations is used to solve for the cable geometry parameter, y .

$$y = \frac{1}{2} [E(1+\xi\eta) + L[(\xi^2-1)(1-\eta^2)]^{1/2}] \quad (1.6.0)$$

$$\text{where } \xi = \frac{\bar{S}_o}{(L^2 + E^2)^{1/2}} \quad (1.6.1)$$

$$\eta = \frac{-b \pm \sqrt{b^2 - ac}}{a} \quad (1.6.2)$$

$$a = \xi^2 + \frac{E^2}{L^2} (\xi^2 - 1) \quad (1.6.3)$$

$$b = \xi \left(1 - \frac{2d}{L}\right) \quad (1.6.4)$$

$$c = \left(1 - \frac{2d}{L}\right)^2 - \frac{E^2}{L^2} (\xi^2 - 1) \quad (1.6.5)$$

The sign of the radical in equation 1.6.2 is the same as the sign of the elevation difference, E .

Log Geometry

The log geometry is specified for the sole purpose of determining the partial suspension load factors, which are given by the following equations:

$$v = \frac{\tan \alpha (\sin \theta + \mu \cos \theta)}{(\cos \theta - \mu \sin \theta) + \tan \alpha (\sin \theta + \mu \cos \theta)} \quad (2.1.0)$$

$$h = \frac{\sin \theta + \mu \cos \theta}{(\cos \theta - \mu \sin \theta) + \tan \alpha (\sin \theta + \mu \cos \theta)} \quad (2.2.0)$$

Before equations 2.1.0 and 2.2.0 can be solved the angle from the horizontal to the choker, α , must be known. This is done with an iterative procedure for the simultaneous solution of equations 2.3.0 and 2.4.0.

$$\alpha = \tan^{-1} \left[2 \tan(\theta + \beta) + \frac{\cos \theta - \mu \sin \theta}{\sin \theta + \mu \cos \theta} \right] \quad (2.3.0)$$

$$\beta = \sin^{-1} \left[\frac{y_c \cos \theta - 1_c \sin(\alpha - \theta)}{1_l} \right] \quad (2.4.0)$$

Equation 2.3.0 is valid only if the ground-to-log angle, β , is greater than zero (Carson 1975). For yarding situations where this angle is zero, the choker angle can be determined directly from equation 2.5.0.

$$\alpha = \sin^{-1} \left(\frac{y_c}{1_c} \cos \theta \right) + \theta \quad (2.5.0)$$

The carriage clearance, y_c , used in equations 2.4.0 and 2.5.0 for the live and running skyline is the same as the minimum required load clearance, h_L . For the standing skyline, y_c is taken to be equal to the variable load clearance, h_L , given by equation 2.6.0.

$$h_L' = (Y_Y + h_Y) - (Y_L + y) \quad (2.6.0)$$

where y is from equation 1.6.0.

The equations giving the load factors, v and h , were generated by assuming a homogenous, cylindrical column of negligible diameter to length ratio. The error introduced is minimal compared to the uncertainty of the log's weight distribution, the leading end, the choker placement, and scale allowance for log length.

Payload Calculations

The payloads that will cause the tensions to reach the allowable limit are given by the following systems of equations for running skylines and for live and standing skylines when a mainline is needed for carriage control.

$$W_n(T_1) = \frac{(V_1 + fV_2) - \frac{y}{d}(H_1 - fH_2) - W_c - \frac{W_3}{2}}{[v - (\frac{y}{d})h]} \quad (3.1.0)$$

$$V_1 = \frac{2T_1^c \omega_1 y + \omega_1^2 y^2 - W_1^2}{2W_1} \quad (3.1.1)$$

$$H_1 = [(T_1^c)^2 - (V_1)^2]^{1/2} \quad (3.1.2)$$

$$V_2 = \frac{2T_1^c \omega_1 (y-E) + \omega_1^2 (y-E)^2 - W_2^2}{2W_2} \quad (3.1.3)$$

$$H_2 = [(T_1^c)^2 - (V_2)^2]^{1/2} \quad (3.1.4)$$

$$W_1 = \omega_1 [(y)^2 + (d)^2]^{1/2} \quad (3.1.5)$$

$$W_2 = \omega_1 [(y-E)^2 + (L-d)^2]^{1/2} \quad (3.1.6)$$

$$W_3 = \omega_3 [(y)^2 + (d)^2]^{1/2} \quad (3.1.7)$$

$$T_1^c = T_1 - \omega_1 y \quad (3.1.8)$$

$$W_n(T_3) = \frac{V_3 - \left(\frac{V_1 + fV_2}{H_1 - fH_2} \right) H_3 - W_c}{[v - \left(\frac{V_1 + fV_2}{H_1 - fH_2} \right) h]} \quad (3.2.0)$$

$$V_3 = \frac{2T_3^c \omega_3 y + \omega_3^2 y^2 - W_3^2}{2W_3} \quad (3.2.1)$$

$$H_3 = [(T_3^c)^2 - (V_3)^2]^{1/2} \quad (3.2.2)$$

$$T_3^c = T_3 - \omega_3 y \quad (3.2.3)$$

The following expressions yield the payloads when a haul-back is needed on live and standing skylines.

$$W_n(T_1) = \frac{(V_1 + V_2) + \left(\frac{y-E}{L-d} \right) (H_1 - H_2) - \frac{W_4}{2} - W_c}{[v + \left(\frac{y-E}{L-d} \right) h]} \quad (3.3.0)$$

$$W_n(T_4) = \frac{V_4 + \left(\frac{V_1 + V_2}{H_1 - H_2} \right) H_4 - W_c}{v - \left(\frac{V_1 + V_2}{H_1 - H_2} \right) h} \quad (3.4.0)$$

$$V_4 = \frac{2T_4^c \omega_4 (y-E) + \omega_4^2 (y-E)^2 - W_4^2}{2W_4} \quad (3.4.1)$$

$$H_4 = [(T_4^c)^2 - (V_4)^2]^{1/2} \quad (3.4.2)$$

$$W_4 = \omega_4 [(y-E)^2 + (L-d)^2]^{1/2} \quad (3.4.3)$$

$$T_4^c = T_4 - \omega_4 y \quad (3.4.4)$$

The value for the variable f is 1 for live and standing skylines, 2 for running skylines. Some of these equations are based on certain simplifying assumptions similar to the "rigid link" analyses (Carson 1976). However, the errors involved for the vertical and horizontal forces are considerably less and the expressions are much easier to work with. The greatest error is introduced by equations 3.2.0 and 3.4.0 because they assume that the supporting line tension is at the specified allowable tension, but the supporting line tension may be considerably more or less. However, because only the angles at which they act are involved, the error is usually less than about 2 percent.

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A systematic procedure for predicting the payload capability of running, live, and standing skylines is presented. Three hand-held calculator programs are used to predict payload capability that includes the effect of partial suspension. The programs allow for predictions for downhill yarding and for yarding away from the yarder. Equations and the basis principles involved in analyzing skyline systems for allowable payload are presented.

375.1

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