PREDICTING RUNNING SKYLINE PERFORMANCE BASED ON THE MECHANICAL CAPABILITY OF THE YARDER

by

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A PAPER

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Forestry

Completed April 26, 1985

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to the U. S. Forest Service for the opportunity to participate in the Advanced Logging Systems Training Program here at O. S. U. I hope that this paper contributes to the goal of improved planning and layout of Forest Service timber sales.

I would like to thank John Sessions not only for his untiring assistance in the undertaking of this project, but also for the contagious energy he put into all of the classes that I took from him during my stay here at O.S.U.

People who have completed a project such as this can understand the tremendous impact it has on family life. My wonderful wife Kim worked lots of "overtime" to allow me to complete this project. The successful conclusion of my work here is as much due to her dedicated work in the home, as my long hours in the "dungeon." Thank you, Kim.

Finally, I would like to thank Don and Tillie Wilbanks, my parents, for without them, none of this would have been possible.

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I. INTRODUCTION

During the timber sale planning process, the forest engineer must determine the type of yarding system which can most efficiently harvest the area. In the case of steep, environmentally sensitive terrain, the running skyline system is often an alternative. The first step in the analysis is to determine physical feasibility. Once this is known, yarding costs are estimated in order to help determine the most efficient system.

Currently, skyline analysis programs, available for desk-top computers and hand held calculators, are used to determine the maximum payload which can be supported at various points along the skyline corridor.

The programs are based on the following information:

1. Diameter and length of wire rope recommended for the yarder.
2. Yarder tower height.
3. Profile geometry.
4. Minimum skyline or log clearance.
5. Allowable working tensions.

The rope dimensions and tower height are available from manufacturers' specifications. Profile geometry is obtained from field or map surveys. Minimum skyline clearance is determined as necessary to meet sale objectives. Finally, the engineer must decide what allowable working tensions will be acceptable. Often the tensions are assumed to be the safe working load of the line and the tensioning capability of the yarder is not considered.

After determining that payloads are adequate, production is estimated using available regression equations for cycle time, or "rules of thumb" based on past local experience. Yarding costs can then be calculated as a basis for comparison between systems.

The assumption that the tensioning capability of the yarder is not limiting may not be valid and can result in the predicted payloads being unattainable. In addition, the yarder may be unable to deliver the power necessary to achieve the predicted production rates. Consequently, actual production could fall significantly below that originally estimated.

In order to more accurately predict running skyline performance, this paper presents a method for modeling the interaction between the yarder, the load, and the terrain. To accomplish this, profile geometry is established using conventional methods. Carriage position is then found based on an assumed payload, and the tensioning capability of the yarder. Next, torque required at the mainline drum to support the load is calculated. The operating condition of the engine/drive train that can deliver the required torque is then determined. Finally, line speed is calculated based on engine speed, torque converter speed ratio, drum set gearing, and effective radius. To do this, power flow must be defined for the specific running skyline. Each component of the yarder is modeled to permit simulation of the inhaul element of the yarding cycle.

The Agricultural Engineering Department of the University of California at Davis is currently doing work on modeling the drive trains of various running skyline yarders. Their research does not include the interaction of the yarder with the choosen load and profile.

Objective

The objective of this paper is to develop a methodology for determining running skyline yarder performance based on the mechanical characteristics of the yarder and its interaction with the load and the terrain. A code for implementing this procedure on the HP-9020 will be prepared.

Scope

This paper will consider the following three designs of running skyline yarders.

1. Non-interlocked
2. Mechanical interlock

3. Variable ratio hydraulic interlock

The three designs will be modeled in the uphill configuration only. That is, when the engine must supply positive torque to drive the system rather than negative torque to slow the system down. Analysis will be limited to the inhaul element of the yarding cycle. The line configuration consists of a mainline and haulback shackled to the carriage. The line segments are assumed to act as "rigid links" as suggested by Carson (1976).

II. YARDER POWER FLOW

Power flow must be considered in order to predict yarder performance. Power delivered into the system must equal power leaving the system. Since the purpose of a yarder is to bring a load of logs to the landing, the minimum input power requirement would be the power necessary to perform useful work on the load. Therefore, other sources of power loss can be considered inefficiencies in the system. The relative efficiency of a running skyline yarder is defined here as the power necessary to do the required work on the load and lines, divided by the total power input by the engine. This measure of efficiency can be used to compare the abilities of different designs to deliver power to the load. The power flow between the yarder, the lines, and the load varies with each design. Mann (1977) described power flow in running skyline yarders.

Non-interlocked

The non-interlocked running skyline is the simplest and least efficient of the three designs. The yarder may be equipped with a multi-stage torque converter without a gearbox, or a single stage converter with a power shift gearbox. The power lost in the converter can vary from 5% to 50% depending on design and operating condition. Power flows from the converter output shaft to the mainline drum. The mainline drum then transmits the power to the mainline. At the carriage, some power flows to the load to do the work required to yard the turn, while the rest is transferred to the haulback line. Power leaves the haulback line at the large water-cooled brake which is used to maintain tension in the system (Figure 1.).

Mechanical Interlock

Power flow in the mechanical interlock is the same as the non-interlocked design except that a portion of the power at the haulback drum is recycled back to the mainline drum. This is accomplished by placing a clutch between the haulback and mainline drum gears (Figure 2.). This regenerative clutch substantially reduces the input torque required from the engine. To transfer power from the haulback drum to the mainline drum, the angular speed of the haulback side of the clutch must always be greater than the mainline drum side of the clutch. In the absence of any intermediate gearing between the drums, this can be accomplished by selecting drum radii which allow the effective radius of each drum to be equal when the carriage is at the tailhold of the longest possible span. At this position the haulback drum is nearly full and the mainline drum virtually empty. Assuming equal line speeds, there is no slip across the clutch at this point. This is known as the "lock-point". As inhaul progresses, the haulback loses line reducing its effective radius, while the

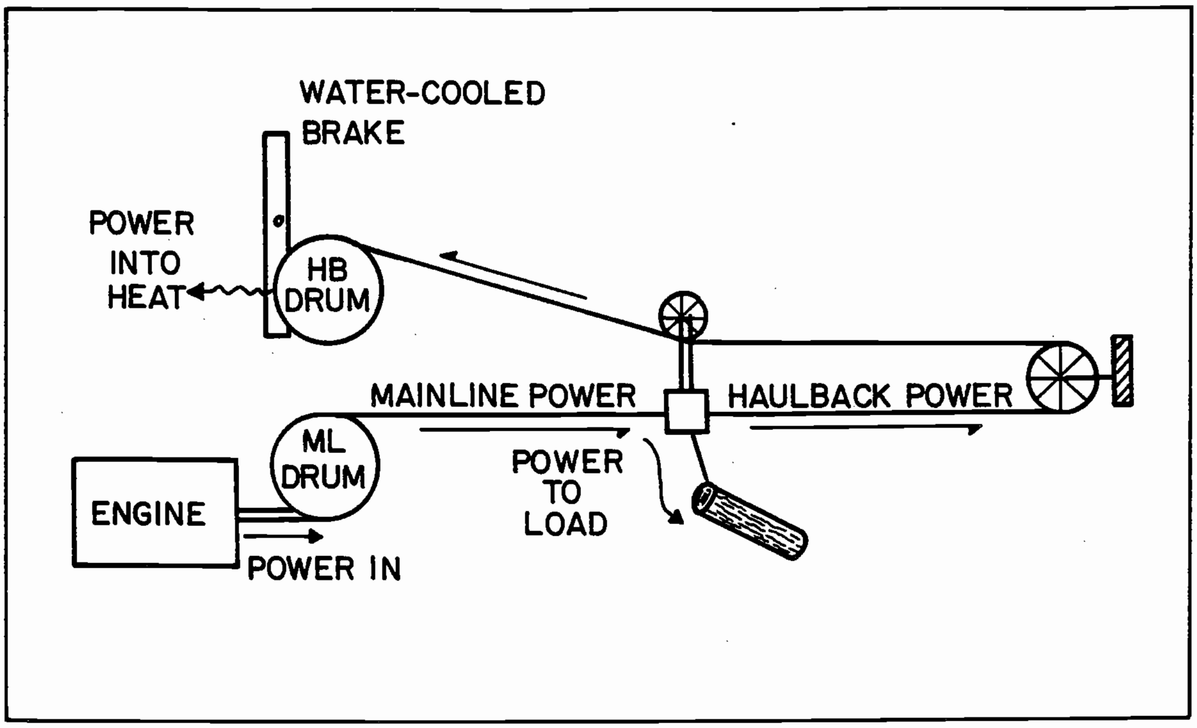

Figure 1. Power flow in a non-interlocked running skyline

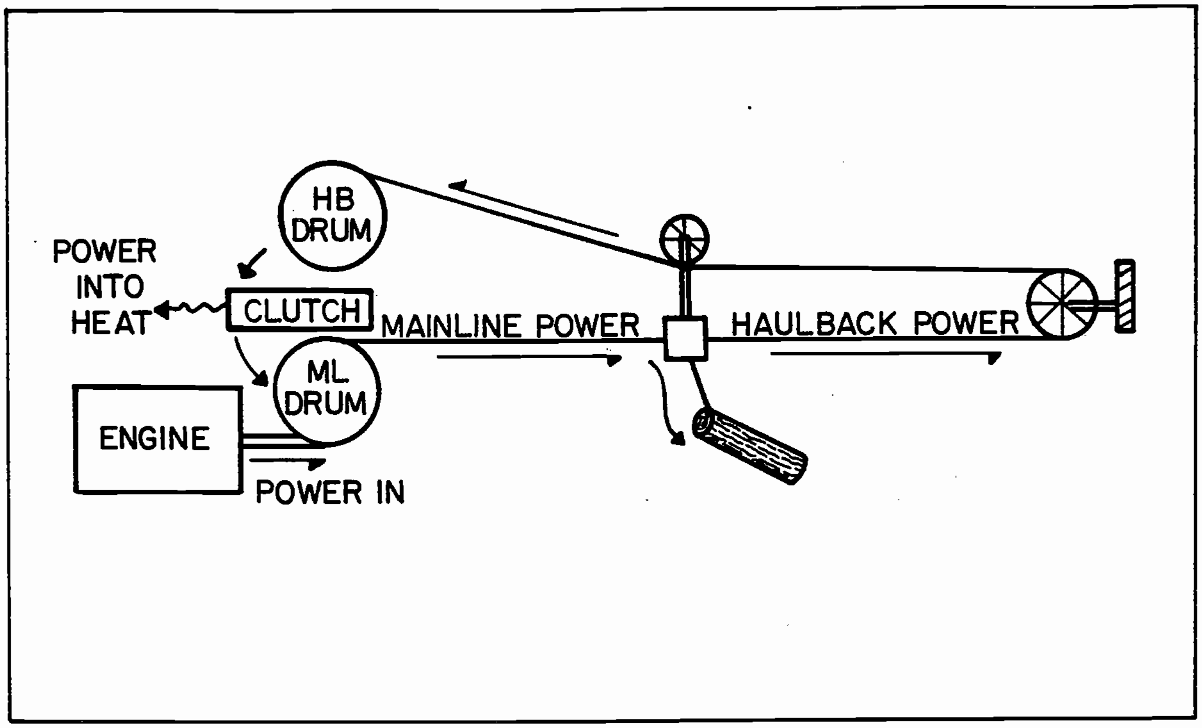

Figure 2. Power flow in a running skyline with a mechanical interlock

main drum gains line, increasing its radius. The net effect is the haulback drum begins to speed up relative to the mainline drum. The differential speed is greatest when the carriage nears the landing. In practice, intermediate gearing is used to control the location of the lock point rather than drum radii. Since the mainline and haulback speeds are rarely equal, the differences between them must be accounted for when calculating differential speed. The differential speed (Δn) is expressed as:

$$\Delta n = n_m \quad \frac{(r_m)(H_v)}{(r_h)(M_v)} - \frac{(n_h/n_i)}{(n_m/n_i)} \tag{1}$$

where:

n_m = angular speed of the mainline drum gear

n_h = angular speed of the haulback drum gear

n_i = angular speed of the intermediate drive pinion

r_m = mainline drum effective radius

r_h = haulback drum effective radius

H_v = haulback line speed

m_v = mainline speed

Differential speed is necessary to calculate the amount of power dissipated at the clutch face (P_1). Power dissipated is the product of differential speed and the torque transferred across the clutch (M_c).

$$P_1 = \frac{(\Delta n)(M_c)}{5252} \tag{2}$$

The power dissipation capability of the clutch varies with design. Line speeds and/or clutch torque may be limited in some situations so that power absorbed does not exceed manufacturers recommendations. This is less of a concern with water-cooled clutches than with air-cooled clutches. Information on clutch power absorption capacity is available from manufacturers.

Interlock Efficiency

Efficiency is the ratio of power-out to power-in. In this case, power-in is the power on the haulback side of the clutch, and power-out is the power on the mainline side of the clutch. Since torque is equal on both sides of the clutch, the efficiency of the mechanical interlock (E_i) can be defined as the speed of the mainline side of the clutch divided by speed of the haulback side of the clutch. This speed ratio is dependent on drum radius ratio, line speed ratio, and the speed ratio between the mainline gear and the haulback gear. Interlock efficiency can be mathematically expressed as:

$$E_i = \frac{(r_h)(M_v)(n_m/n_i)}{(r_m)(H_v)(n_h/n_i)} \tag{3}$$

The mechanical interlock substantially reduces the power required to obtain loads and line speeds comparable with those of the non-interlocked yarder.

Variable Ratio Hydraulic Interlock

One type of variable ratio interlock utilizes a hydrostatic drive to continually vary the speed ratio between the haulback and mainline drums as necessary to control their relative speed. The two drums are interlocked by placing a hydraulic vane motor between them. The haulback drive pinion is attached to the motor housing and the intermediate shaft is spliced to the rotor. The mainline drum is geared to the intermediate shaft (Figure 3.).

Unlike the mechanical interlock the geared speed ratio between the main and haulback drums is selected so that the lock-point occurs near the mid-point of the longest possible span. Once again assuming equal line speeds, the theoretical angular velocity of the haulback drum is less than that of the mainline drum from the tailhold to the lock-point, where the rotational speeds match. From the lockpoint to the landing, the haulback drum will begin to turn progressively faster relative to the mainline drum.

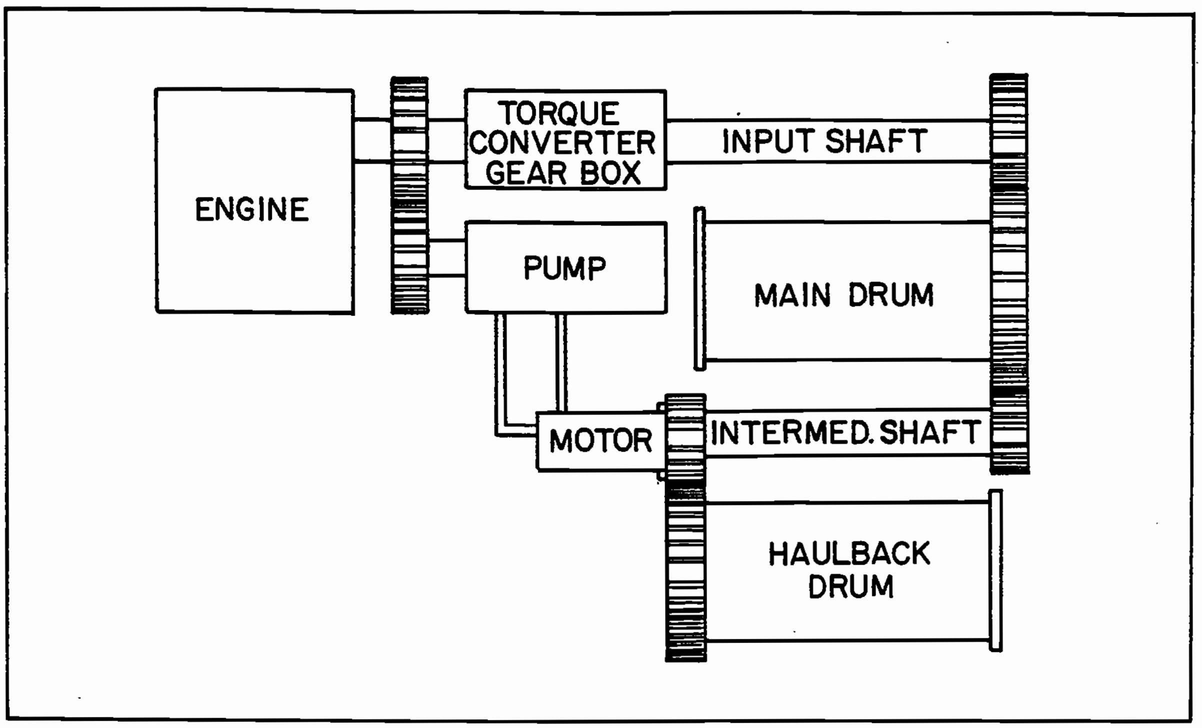

Figure 3. Drum set of a running skyline with a variable ratio hydraulic interlock

When the haulback drum turns slower than the mainline drum, speed must be added through the interlock. This requires a positive flow of power from the engine, through the hydrostatic drive, to the drums. If the haulback drum is rotating faster than the mainline drum, power must be absorbed by the hydraulic motor and transmitted back to the output shaft of the engine through the pump. This negative power flow reduces the amount of torque the engine has to supply to meet tensioning requirements of the main line drum (Figure 4.).

Interlock Efficiency

The efficiency of the variable ratio interlock is dependent on the overall efficiency of the hydrostatic drive. Typical values range from 75% to 95%. To calculate interlock efficiency, the direction of power flow must be considered (Carson, 1972). The power at the hydraulic motor (P_m) is the product of differential speed and torque output. The power at the pump (P_p) depends on the direction of flow. For positive flow from the pump to the motor P_p equals P_m/E_i, and for negative flow from the motor to the pump P_p equals $P_m{*}E_i$. Power loss is calculated as follows:

Positive flow,

$$P_l = \frac{P_m(1-E_i)}{E_i} \qquad (4)$$

Negative flow,

$$P_l = -P_m(1-E_i) \qquad (5)$$

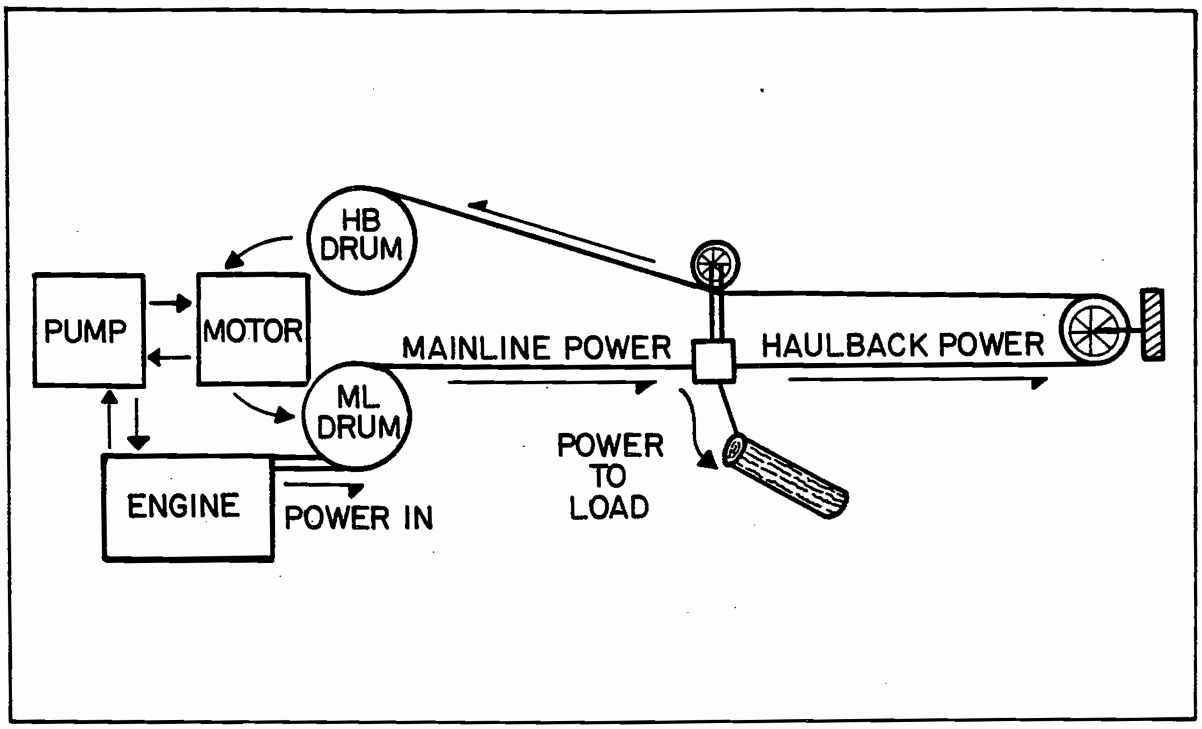

Figure 4. Power flow in a running skyline with a variable ratio hydraulic interlock

III. MODELING YARDER COMPONENTS

In order to estimate performance, each component of the yarder must be modeled. These include the engine, torque converter, gearbox, and drumset.

Engine

Performance curves showing torque characteristics of engines are available from manufacturers. These curves describe engine torque output versus speed at the full throttle setting. The performance curves are based on dynamometer tests and usually must be derated for such basic components as fan, alternator, air compressor, etc. The deduction for auxiliary equipment is approximately 7 to 8 percent.

The engine can be modeled using piecewise linear regression of manufacturer's published data (Figure 5.). The result is an equation, or group of equations, which will predict engine output torque as a function of engine speed.

Torque Converter

The torque converter is designed to multiply engine torque. As the torque requirement of the load increases, the torque converter responds by automatically increasing the ratio of output torque to engine input torque. This is the

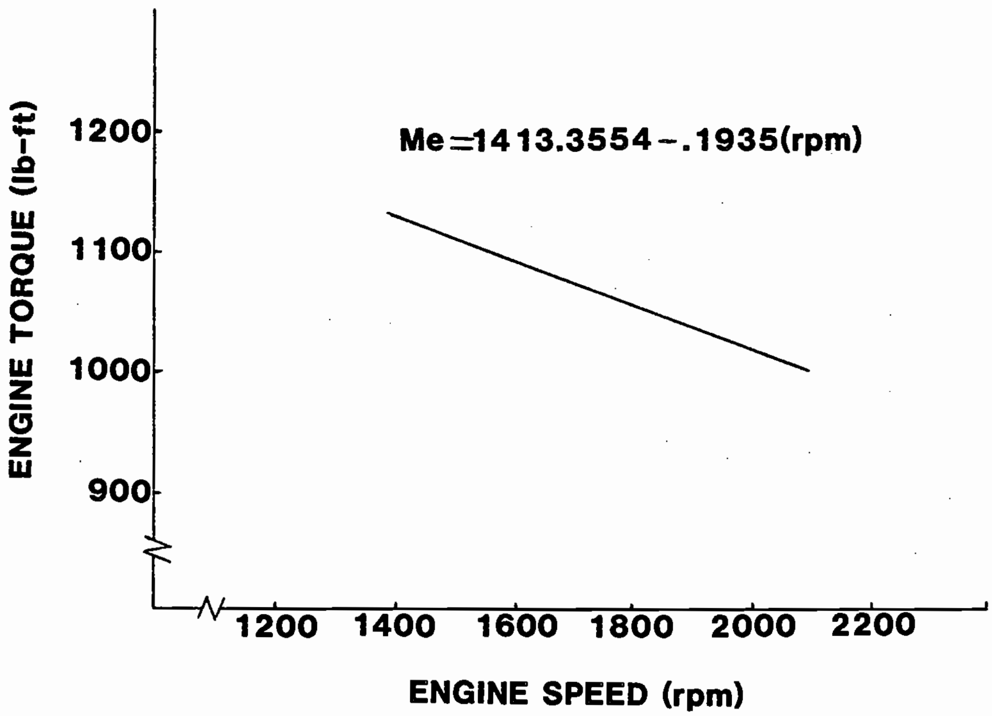

Figure 5. Engine torque as a function of engine speed

same as selecting a lower gear which modifies the power received from the engine, producing more torque and correspondingly less speed. The magnitude of speed reduction and torque multiplication is defined by the speed ratio (Sr_c) and the torque ratio (Tr_c). The speed ratio is the ratio of output speed to input speed. The torque ratio is the ratio of output torque to input torque. The efficiency of the torque converter is the product of the torque ratio and the speed ratio. The torque ratio and speed ratio which result from a particular combination of input power and load conditions, define the operating condition of the torque converter. The converter capacity factor (K_c) is a convenient way of expressing the power input to the converter. The capacity factor is defined by:

$$K_c = n_e/\sqrt{M_e} \tag{6}$$

where:

n_e = engine input speed, rpm

M_e = torque input to converter, ft-lb

The relationship between capacity factor and converter operating condition is established through dynamometer tests. The results of these tests are available from manufacturers in the form of torque absorption charts or converter performance curves. Regression analysis is used to develop relationships for speed ratio as a function of the capacity factor and torque ratio as a function of speed ratio (Figure 6.).

An iterative approach is used to model the converter. The problem is to determine the input torque and input speed that yields the required output torque (M_{out}). Output torque is the torque necessary at the output shaft of the converter to achieve the desired line tension at a given carriage position. Calculation of output torque varies with drum set design, and will be discussed in more detail later.

The iterative solution begins by selecting an initial operating condition for the engine. The converter capacity factor is then calculated. Next, speed ratio and torque ratio are determined using the regression relationships previously developed. If the proper input power has been chosen, the torque ratio as defined by the converter operating condition (Tr_c) must equal the ratio of output torque to input torque (Tr). If this is not the case, input torque must be adjusted until these two variables balance. Figure 7. shows how these two parameters vary relative to input torque. If Tr is greater than Tr_c, then input torque must be increased. Similarly, input torque must be decreased if Tr is less than Tr_c. Input torque can be varied by changing engine speed (Figure 5.) or throttle setting. For example, if the engine is assumed to be operating at full throttle and governed speed and input torque must be increased, engine speed is reduced. This results in higher values for input torque. The

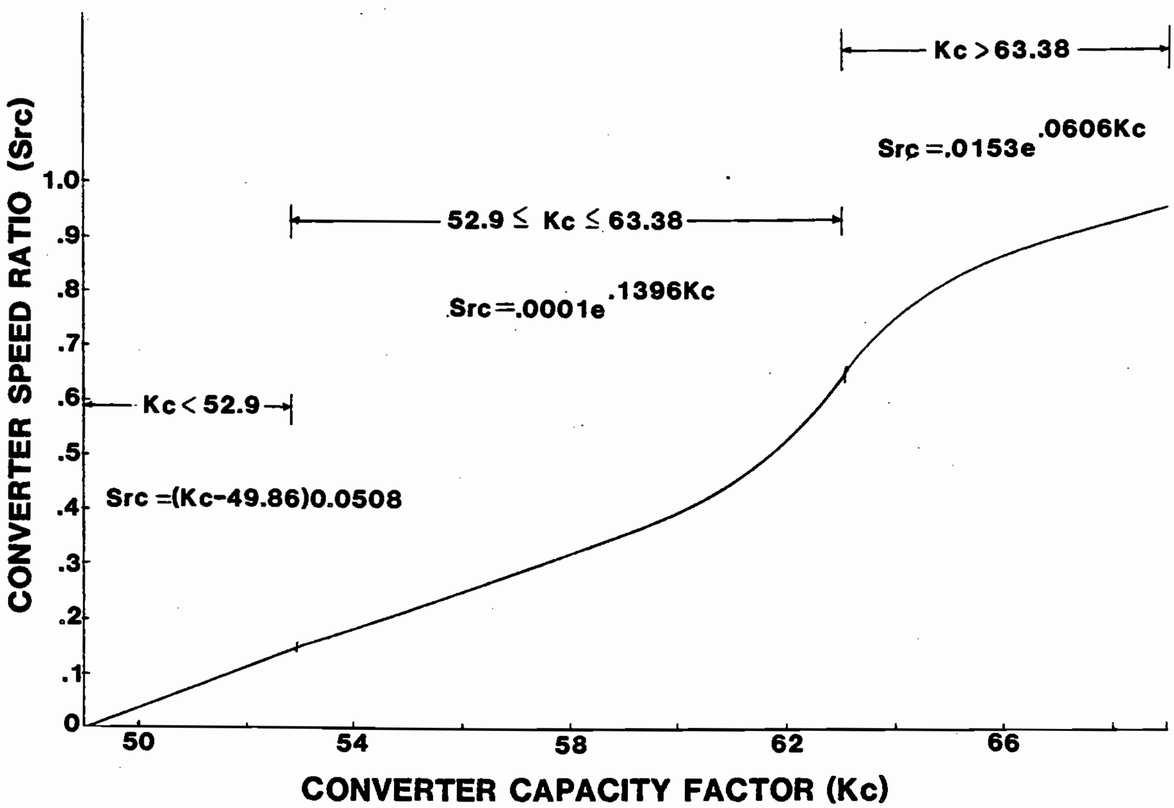

Figure 6. Example of relationship of speed ratio to converter capacity factor as regressed from performance data.

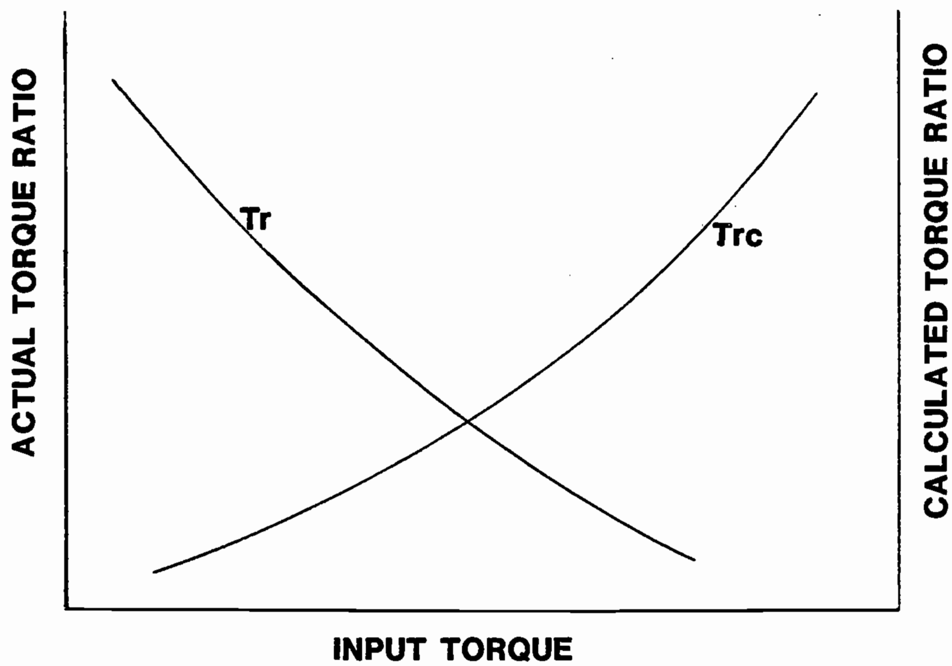

Figure 7. Relationship of calculated torque ratio (Tr_c) and actual torque ratio (Tr) to input torque.

physical interpretation of this is the engine lugging down under heavy torque demand. When the engine is operating at full throttle governed speed the only way to decrease torque is to lower the throttle setting. A binary search technique is used to converge on the operating point that satisfies the condition that Trc = Tr. A flow chart of the torque converter modeling procedure is shown in Figure 8. Once the operating condition of the engine/torque converter is known the output speed is calculated by multiplying engine speed by the converter speed ratio.

Gearbox

Many yarders are equipped with a gearbox. The gearbox is defined by the speed ratios of each gear. Proper gear selection allows the engine and torque converter to operate in an efficient range. For example, if too high a gear is selected, the converter may not be able to generate a large enough torque ratio to meet demand. When this happens, the converter will stall resulting in an efficiency of zero. In order to model the gearbox, the highest gear is selected initially. After determining the converter operating condition, checks are made to determine if the converter is operating within a desirable range. If not, a lower gear is selected and the process repeated until a feasible combination is found (Figure 9.).

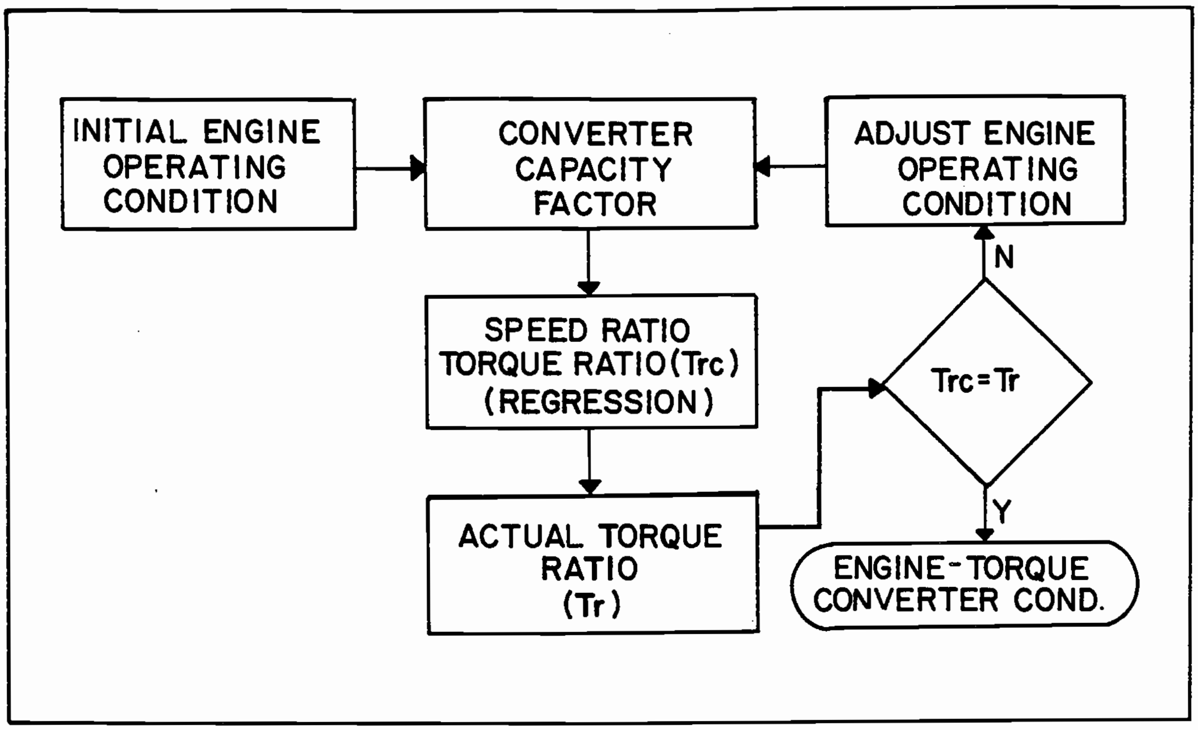

Figure 8. Flow chart of procedure to determine engine-torque converter operating condition.

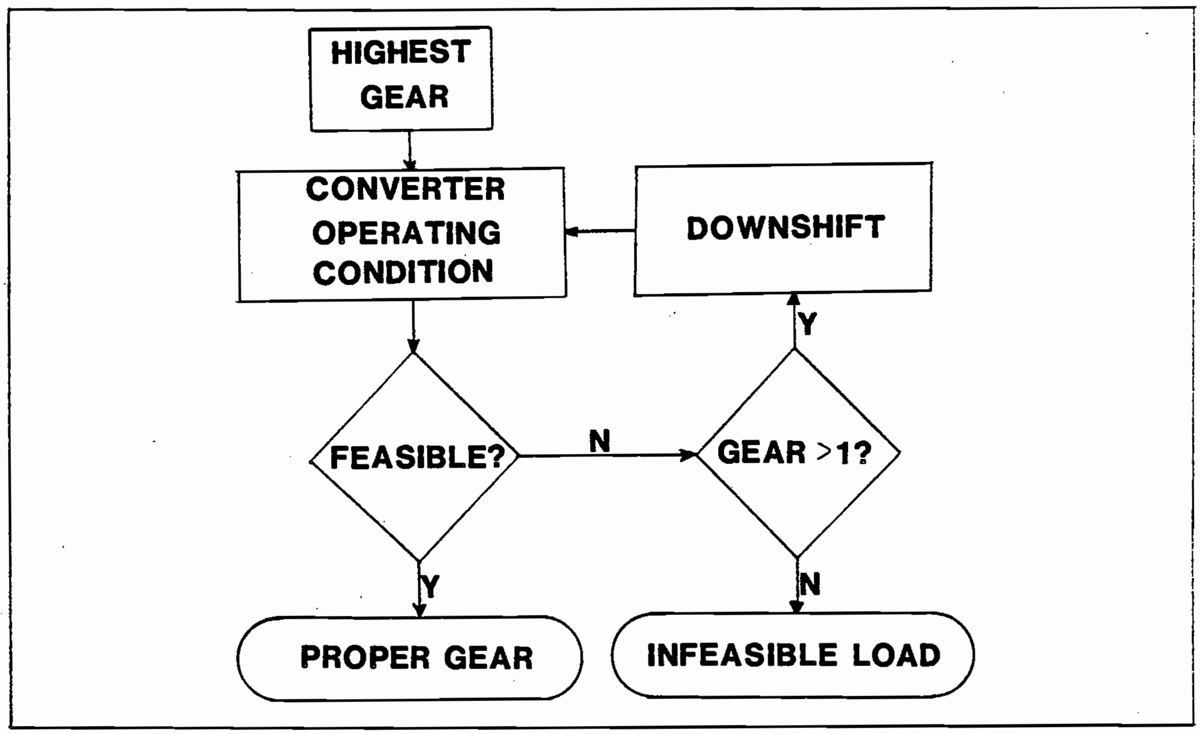

Figure 9. Flow chart of gear selection procedure.

Drum Set

The design of the drum set directly influences: 1) the ability of the yarder to support tension in a specific drum at a specific carriage position, and 2) the torque requirements placed on the power unit during yarding. Two factors that vary with drum set design and have the largest impact are effective drum radius and drum torque.

Effective Radius

The effective radius is the radius as measured from the center of the drum to the center of the outermost layer of the wire rope (Figure 10.). Effective radius varies as line is spooled on and off of the drum during yarding. Assuming that torque (M) delivered to the drum is constant, tensioning capacity is inversely proportional to the effective radius.

This can be illustrated as follows:

$$T = M/r_e \tag{7}$$

where:

T = tension

M = torque delivered to drum

r_e = effective radius of the drum

Referring to Figure 10, as line leaves the drum, r_e will decrease while M, being independent of r_e, will remain constant. The result is an increase in tension. The

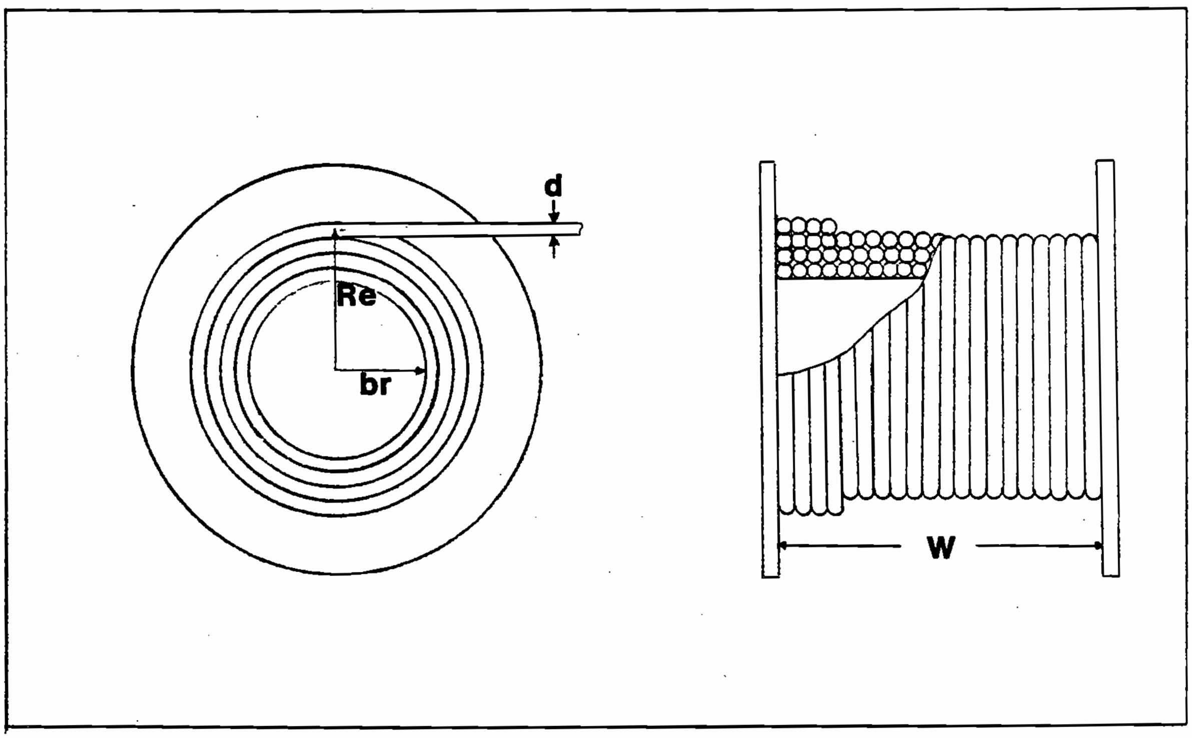

Figure 10. Yarding drum geometry.

effective radius depends on drum geometry, carriage position and the drum under consideration.

Drum geometry controls the range of effective radius as the carriage moves along the span. The wider and larger the drum diameter, the narrower the range of effective radius. For the haulback drum, the effective radius is greatest when the carriage is near the tailhold. As a result, this is the carriage position where the haulback drum produces minimum tension. As the yarder brings in the turn, the tensioning capability of the haulback drum increases to a maximum as the load approaches the landing.

The variation of tensioning capability with carriage position for the mainline drum is opposite that of the haulback. It is highest at the back of the setting and lowest near the landing.

In order to determine tensioning capability, the effective radius of each drum must be calculated at each load point. A convenient way to do this is to calculate the number of "wraps" (layers) of wire rope stored on the drum and then use the following equation.

$$r_e = b_r + (n-.5)d \tag{8}$$

where

b_r = barrel radius empty

n = number of wraps

d = rope diameter

The geometry of a typical yarding drum is shown in Figure 10. The number of wraps on a drum can be calculated using the following equation.

$$n = \frac{-b + \left[b_r^{\,2} + \left(\frac{d^2 L}{KW} \right) \right]^{.5}}{d} \qquad (9)$$

where:

L = length of line on drum, ft

w = width of drum, in

K = .2618

A derivation can be found in Appendix 3.

Drum Torque

Given the effective radius, torque available at a drum controls the amount of tension which can be applied to the line. Drum torque is generated either by the engine through the drive train, or by resisting torque supplied using brakes, clutches or, in the case of hydraulic interlocks, a hydrostatic drive. The engine and drive train will be discussed in detail later. For the moment, assume that torque will not be limited by the engine.

Torque is applied to the mainline drum, from the engine and drive train, through a pulling clutch. In many yarders, this clutch is designed not to limit the tension that can be exerted by the drum. That is, the torque rating of the clutch is adequate to tension the line close to its breaking strength at any effective radius. However, in cases of high tension requirements close to the landing, this clutch may become limiting to mainline tension.

As mentioned previously, the non-interlocked yarder uses a brake, usually water cooled, to tension the haulback line. In the case of the mechanical interlock, the regenerative clutch limits torque available for tensioning the haulback. Torque supplied by clutches and brakes is assumed to increase linearly with the pressure applied to the friction surfaces. The pressure is commonly supplied by compressed air. (Figure 11.). The following relationship is

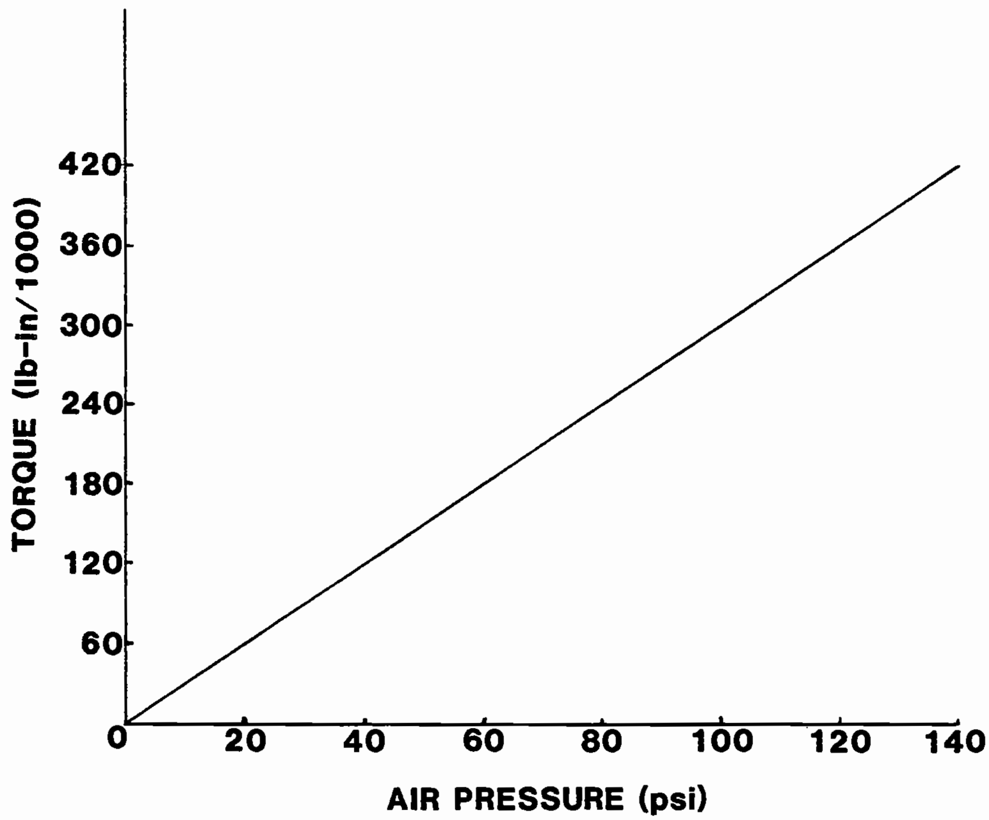

Figure 11. Clutch (brake) torque as a function of applied pressure.

used To calculate the torque capability of clutches or brakes.

$$M = (p)(C_t) \qquad (10)$$

where,

M = Torque, in-lb

p = Air Pressure, psi

C_t = torque constant, in-lb/psi

The constant C_t is dependent on design and is available from the manufacturer.

Example

$C_t = 3000$, $p = 100$ psi

The torque available = (100)(3000)

$M = 300{,}000$ in-lb

This would be the torque available to produce tension in the haulback drum.

The resisting torque in the haulback of a variable ratio hydraulic interlock is supplied by the hydrostatic drive. This device consists of a fixed displacement hydraulic motor placed between the mainline and haulback drums that is supplied with torque through a variable displacement pump driven by the engine. The torque rating, C_h, of the hydraulic motor is a function of the motor design, displacement, and angular speed. The variation of output torque to motor speed is relatively small and can be neglected for the range of speeds involved. Neglecting effects of motor speed, the motor torque can be expressed as the product of the torque rating and the hydraulic pressure differential (Δp) between the inlet and outlet ports of the motor. The torque available at the haulback drum is a function of the hydraulic motor torque and the speed ratio of the haulback to the motor drive pinion (Figure 3.). Therefore, the torque available in the haulback drum of a hydraulically interlocked yarder can be calculated as follows:

$$M_{hb} = \frac{(\Delta p)(C_h)}{n_h/n_i} \qquad (11)$$

where:

M_{hb} = torque at haulback

Δp = pressure differential

C_h = torque rating of motor

IV. RUNNING SKYLINE LOAD PATH

Payload capability is often determined by calculating maximum load carrying capacity for a given haulback tension and deflection (Carson,1976). For the purpose of yarder modeling, a more useful method determines deflection, and ultimately a load path, for a given load and tension. Calculation of the load path yields three important pieces of information relative to yarder modeling.

1) Mainline tension necessary for a static force balance at the carriage.
2) The line speed ratio necessary for the carriage to travel along the load path.
3) Deflection of the skyline, and whether the load is fully or partially suspended.

Two separate procedures are used in load path determination. One treats the fully suspended case while the other deals with partial suspension.

Full Suspension

Analysis of the fully suspended load path was developed by Carson and Mann (Carson and Mann, 1971). A brief summary of this procedure is presented here.

For each terrain point the secant method is used to determine the value for deflection that will provide the desired payload. This method requires two initial guesses for D_y. The initial guess for deflection (D_{yi}) is the value that would put the carriage on the skyline chord. The net payload (W_o) is calculated using the initial estimate of the deflection. For the second guess, a deflection equal to the first guess plus one percent of the span is used. Once again, the corresponding value for payload is calculated. The third, and all successive trials for D_y are determined from the secant formula:

$$D_{y_{new}} = \frac{(W_g - W_o)\ (D_y - D_{yi})}{(W - W_o)} + D_{yi} \tag{12}$$

where:

- W_g = desired net payload
- W_o = previous value for payload
- W = current value for payload
- $D_{y_{new}}$ = new trial deflection
- D_y = current trial deflection
- D_{yi} = previous trial deflection

The method usually converges on D_y in 4 to 8 iterations.

Once the fully suspended deflection is known, the skyline clearance is calculated and checked to verify if full suspension is possible.

Partial suspension

Carson (1975) discussed an algorithm which included the effects of log drag in the determination of the running skyline load path. However, this procedure assumed a known log to ground angle (β) which was constant as deflection varied (Figure 12). This is not the case since deflection is a function of β. Because of this another method was developed. This procedure is somewhat similar to Carson's fully suspended algorithm. Instead of iterating for D_y, the secant method is used to find the log to ground angle that gives sufficient deflection to support the desired payload. The secant method was slightly modified for this procedure. It was found necessary to restrict the search within certain bounds associated with different ground conditions.

Condition 1

Condition 1 consists of the uphill yarding situation. The two initial guesses define the limits of the solution space in the search for β. The first guess assumes the log virtually laying on the ground (Figure 13a.). This initial guess for the log to ground angle ($\beta 1$) is calculated as:

$$\beta 1 = \mathrm{Sin}^{-1}(D/L) + 5$$

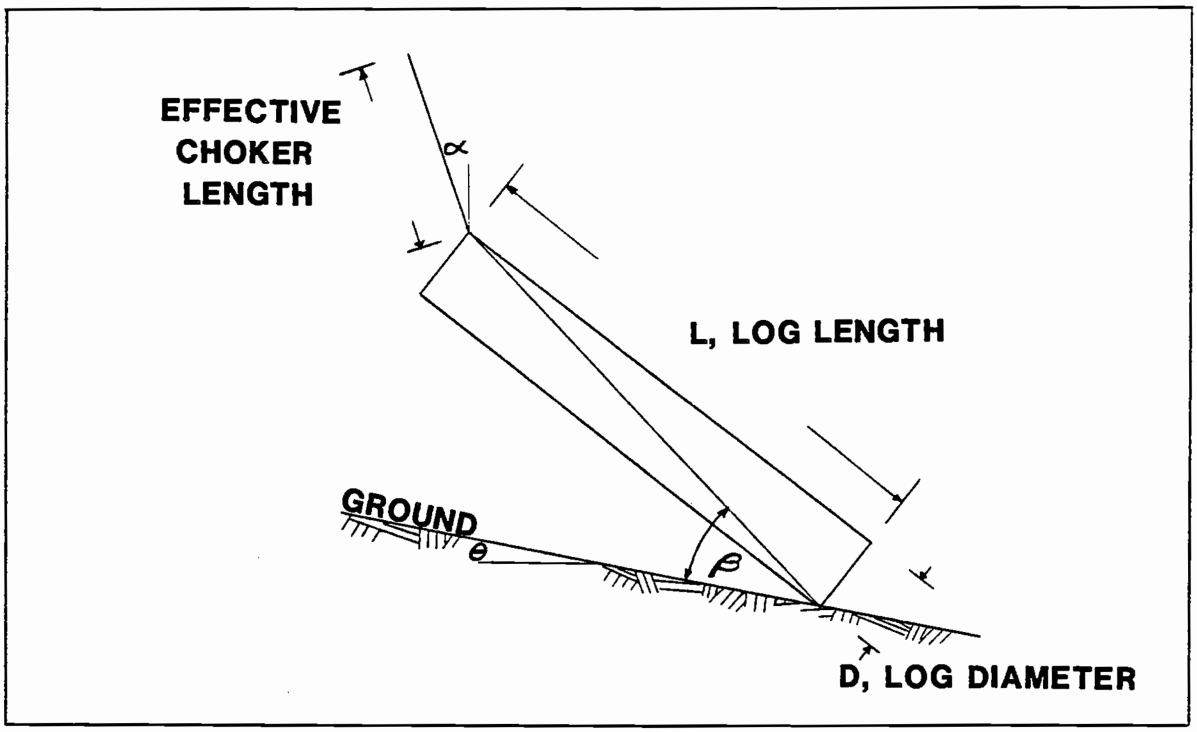

Figure 12. Log drag geometry.

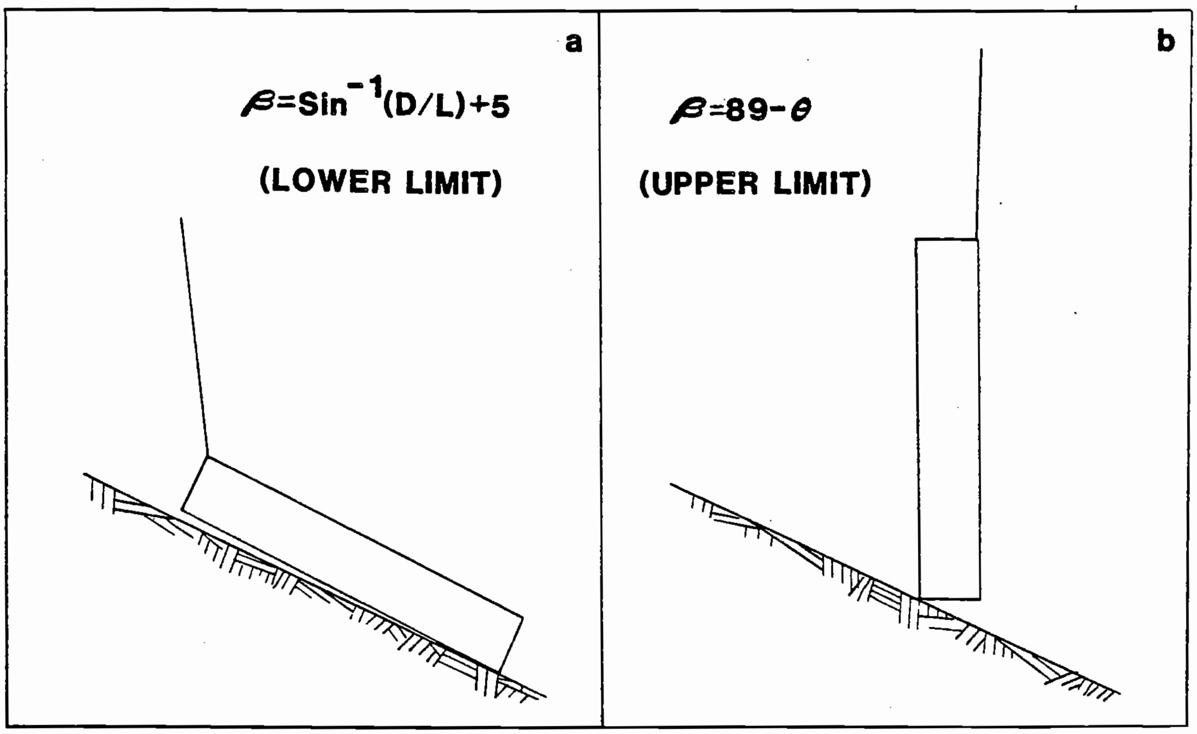

Figure 13. Search limits for log-to-ground angle.

where:

D = log diameter

L = log length

The five degree addition is to insure a high positive value for payload with the initial trial. The second guess for the log to ground angle (β_2) approximates the condition where the log is hanging nearly vertical (Figure 13b) and is calculated as:

$$\beta_2 = 89 - \theta \tag{13}$$

where:

θ = ground slope angle

Eighty nine degrees is used because for flat slopes ($\theta = 0$) the tangent of θ which is used in the denominator of subsequent calculations is zero resulting in an undefined number.

For the third and all successive guesses, the secant formula is used.

$$\beta_{new} = \frac{(W_g - W_o)(\beta - \beta_o)}{(W - W_o)} + \beta_o \tag{14}$$

where:

W_g = desired payload

W_o = previous payload

W = current payload

β = current log to ground angle

If the calculated β_{new} does not fall within β_1 and β_2, it is arbitrarily adjusted to fall within these limits. This process eliminates extraneous values of β, and considerably speeds up the iteration procedure. Four to ten iterations are normally needed to obtain values for payload within two percent of the desired load.

Condition 2

Condition 2 occurs when the log is moving down hill and the ground slope is less than the coefficient of friction. The two initial guesses for this condition are the same as for condition 1. Figure 14. illustrates the log to ground geometry.

Condition 3

Condition 3 is when the ground slope is greater than the coefficient of friction as the log moves down hill. Since ground slope (decimal percent) is greater than the coefficient of friction, the log must be held on the slope by the haulback (Figure 15.).

It would have to be very steep for the log to actually run ahead of the carriage. However, this log to ground geometry is consistent with the static analysis of forces which is a major assumption in this analysis. Once again, trials for β are held within the solution space defined by the two initial guesses. Four to ten iterations are necessary

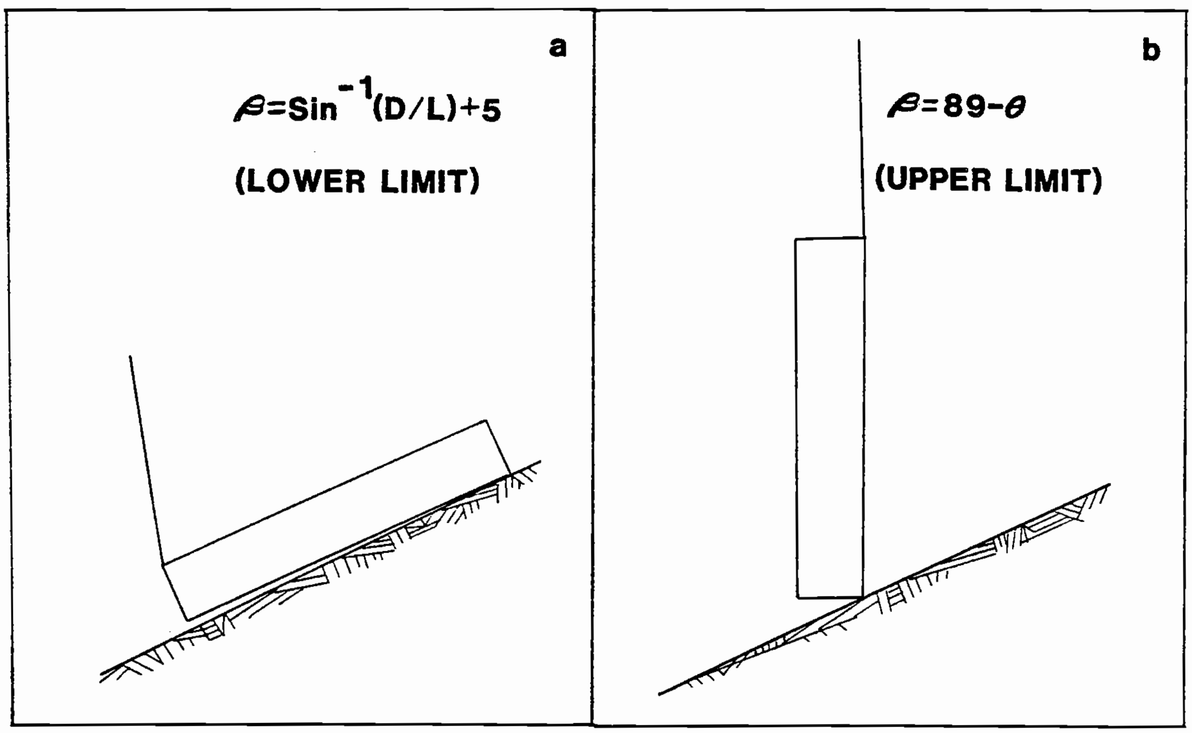

Figure 14. Search limits for downhill yarding with ground slope less than ooefficient of friction.

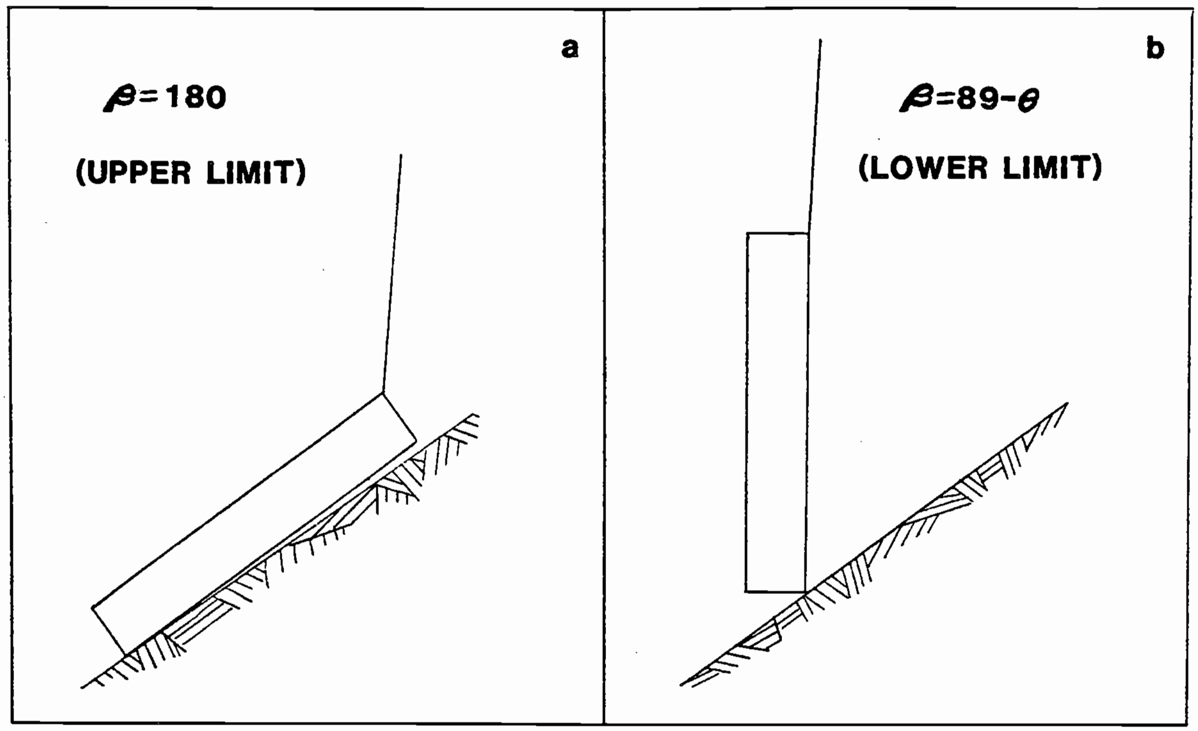

Figure 15. Search limits for downhill yarding with ground slope greater than coefficient of friction.

in order to find a log to ground angle which yields payloads within two percent of the desired load (Figure 16.).

Once the load path is established, mainline tensions at each terrain point are known. These tensions are used with mainline effective radius to determine the torque requirement at the mainline drum. Finally, the line speed ratio is calculated to determine the amount of power which is delivered to the haulback drum during inhaul. Line speed ratio is expressed as follows:

$$L_{srat} = \frac{HV}{MV}$$

where: MV = mainline speed
HV = haulback speed

It can be rewritten as

$$L_{srat} = \frac{\frac{\Delta Hl}{time}}{\frac{\Delta Ml}{time}}$$

where: ΔMl = change in length of mainline out
ΔHl = change in length of haulback line out.

The two time terms cancel out and leave:

$$L_{srat} = \frac{\Delta Hl}{\Delta Ml}$$

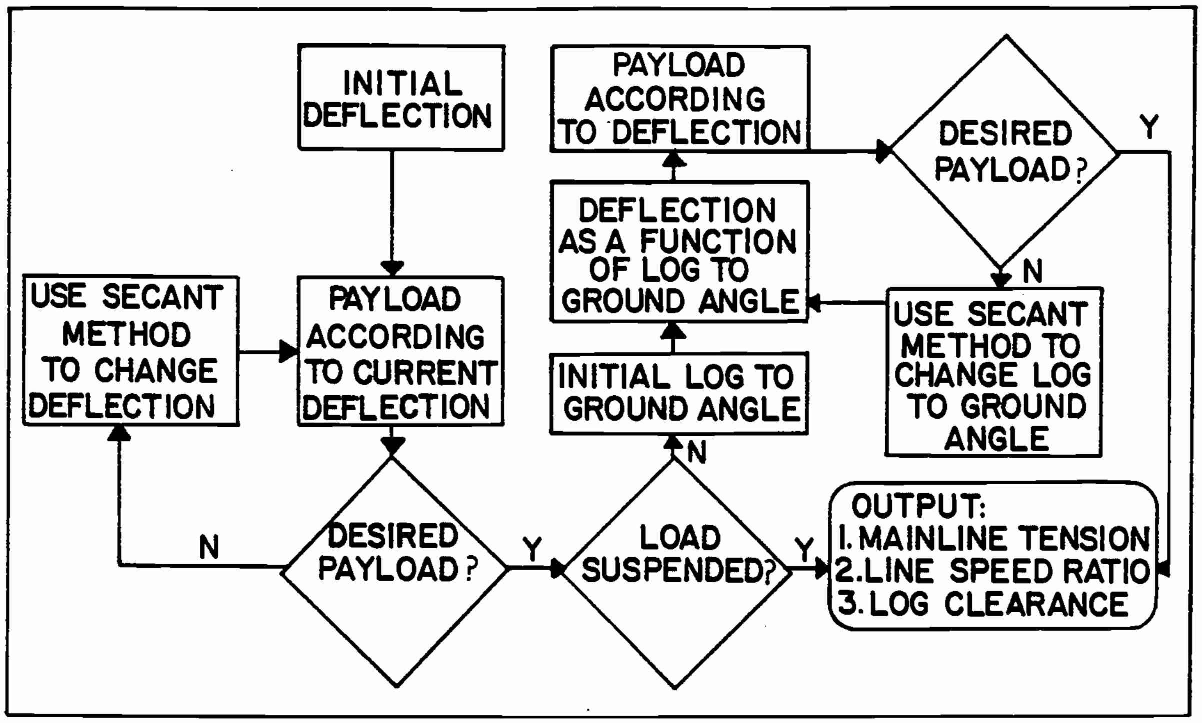

Figure 16. Flow chart of procedure for load path analysis.

The value for $\Delta M1$ or $\Delta H1$ can be readily calculated from the information obtained during the load path calculations. The pythagorean theorem is used to determine the total amount of haulback and mainline out at each terrain point. Less averaging error is introduced if the terrain points are very close together. The closer the points, the closer the calculated value will approximate the differential value for line speed ratio. This can be done by adding "dummy" terrain points immediately on the tailhold side of the field measured terrain points (Figure 17.). The procedure for adding the extra points can be found in the program listing (Appendix 2).

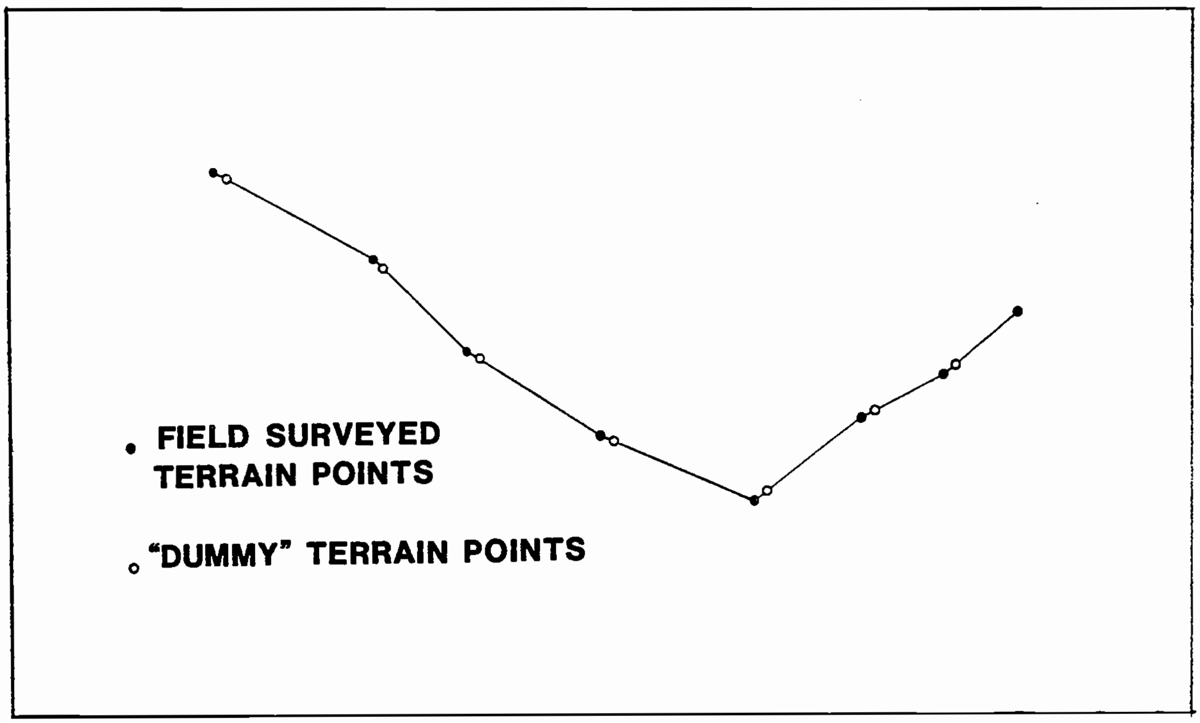

Figure 17. Location of "dummy" terrain points
on skyline profile.

V. ESTIMATING LINE SPEEDS

Once the load path has been established, the line speeds at each terrain point may be calculated.

Non-interlocked

Of the three types of machines considered in this paper, the non-interlocked yarder is the simplest to model. All of the power in the haulback line is dissipated through the haulback brake. The engine and torque converter merely have to respond to the required mainline drum torque at each terrain point. Once the converter operating condition is found, the mainline speed (M_v) is calculated using the following equation.

$$M_v = n_{out} (R) (2\pi r_m)$$

where:

n_{out} = converter output speed, rpm

R = the total reduction from the converter output shaft to the mainline drum.

r_m = mainline drum effective radius

Mechanical Interlock

Modeling of mechanical interlock yarder differs from the non-interlocked yarder in the calculation of torque required at the converter output shaft. The formula for calculating output torque is.

$$M_{out} = \frac{\left[M_{ml} - (M_{hb})(n_h/n_m)\right](R)}{E} \tag{14}$$

where:

M_{ml} = total torque required at the mainline drum.

M_{hb} = torque available through the regenerative clutch.

n_h/n_m = speed ratio from the haulback gear to mainline gear.

E = overall efficiency

After the algorithm converges on the torque converter operating point, the line speeds are calculated in the same manner as for the non-interlocked yarder.

Variable Ratio Hydraulic Interlock

The variable ratio hydraulic interlock is the most complex of the three designs and, therefore, the most difficult to model.

After completing the load path phase of the program, total torque requirement at the mainline drum is known. Converter output torque is then calculated as follows:

$$M_{out} = \frac{\left[M_{ml} - (M_h)(n_i/n_m)\right] (R)}{E} \qquad (15)$$

where:

M_h = torque at the hydraulic motor

n_i/n_m = speed ratio from the intermediate shaft to the mainline drum gear.

The torque converter operating condition must now be determined. This is complicated by the design of the interlock.

In order to calculate the converter capacity factor, the input torque must be known. This was straight forward in the two previous cases discussed. However, as illustrated in Figure 3, the power take off for the pump is between the engine and torque converter. As a result, the input torque to the converter is found by subtracting the amount of torque added (or absorbed) by the pump from the engine torque. Therefore, the capacity factor can be written:

$$K_c = \frac{n_e}{(M_e - M_p)^{.5}} \tag{16}$$

where:

M_p = pump torque

Pump torque will be positive when the hydrostatic drive is adding power to the drums, and negative when it is absorbing power from the drums.

As in the case of the hydraulic motor, pump torque is a function of displacement and pressure differential. The pressure differential is held constant. Pump displacement is varied so that pump flow equals motor flow. Motor flow is the product of differential speed and displacement. Pump speed is proportional to engine speed. The ratio of pump speed to engine speed is available from the manufacturer.

Once the desired pump displacement (D_p) is known, pump torque (M_p) is calculated as follows:

$$M_p = \frac{(D_p)(\,psi)}{24\pi} \tag{17}$$

A derivation can be found in Appendix 3.

The direct solution for pump torque involves the simultaneous solution of six equations and six unknowns. An iterative method for the calculation of pump torque is used. Initially pump torque is assumed to be zero. Converter capacity factor, speed ratio, mainline speed, differential speed, and pump displacement are then computed. Based on these values, an improved value for pump torque is calculated. This value is compared to the previous value. If they are not within some acceptable tolerance, the calculations are repeated using the improved value for pump torque until the difference between them is within acceptable limits (Figure 18.).

The program enters the torque converter phase each time a value for pump torque is found. This is repeated until the engine/converter operating condition is determined. At this point, mainline speed is calculated in the same manner as the other yarder designs.

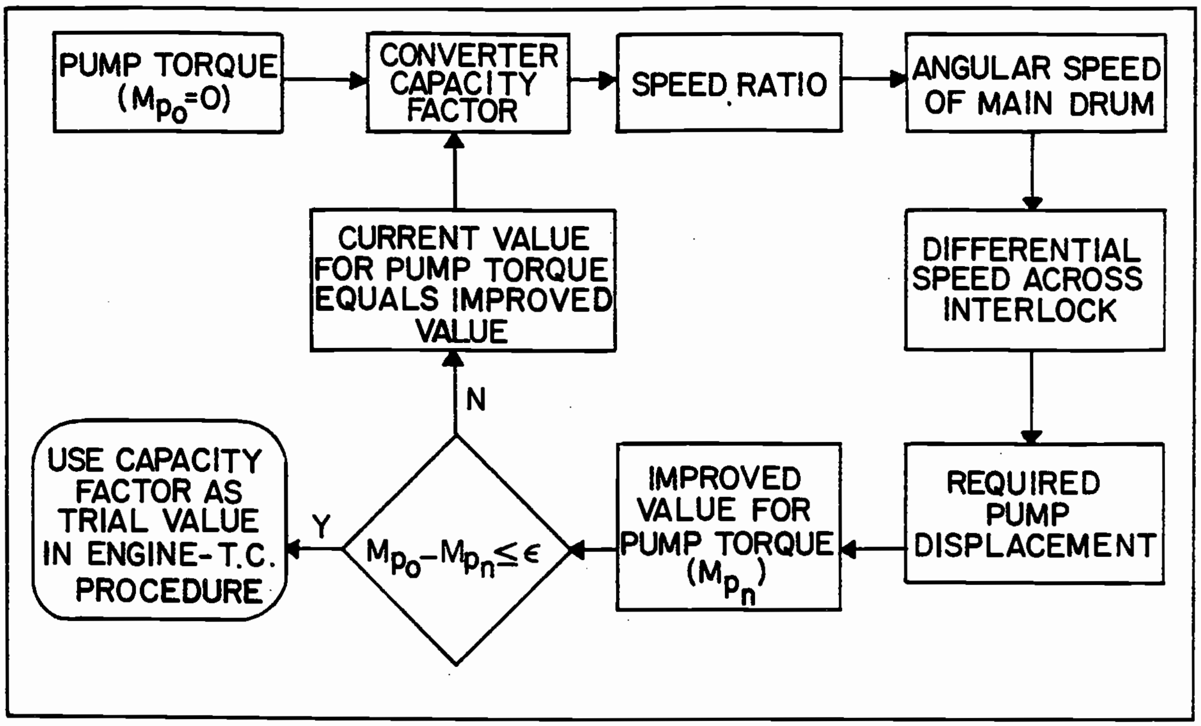

Figure 18. Flow chart of procedure for calculating pump torque.

VI. RESULTS

Three computer programs, which utilize the methodology presented in this paper for predicting running skyline performance were written for use on the HP-9020. Complete program listings and numerical examples are included in the Appendix. A representative yarder was selected from each design category. Figure 19a shows the relative efficiency of the three machines yarding over the same profile. Figure 19b shows the engine power relative to power consumed by the load if all three yarders could inhaul the same load at equal speeds. In practice, a non-interlocked yarder could probably not move a given load as fast as an interlocked yarder because of the extremely high power input and dissipation requirements. The shape of the plots in Figure 19 reflect the overall design of the machine.

For example, near the tailhold the relative efficiency of the mechanical interlock yarder drops-off markedly, whereas the efficiency of the variable ratio interlock yarder continues to increase to a maximum in excess of one hundred percent. The difference in efficiency is largely due to the different torque converters used in each yarder. The mechanical interlock yarder in this case is equipped with a torque converter and a two-speed gearbox. While the variable ratio interlock uses a different torque converter

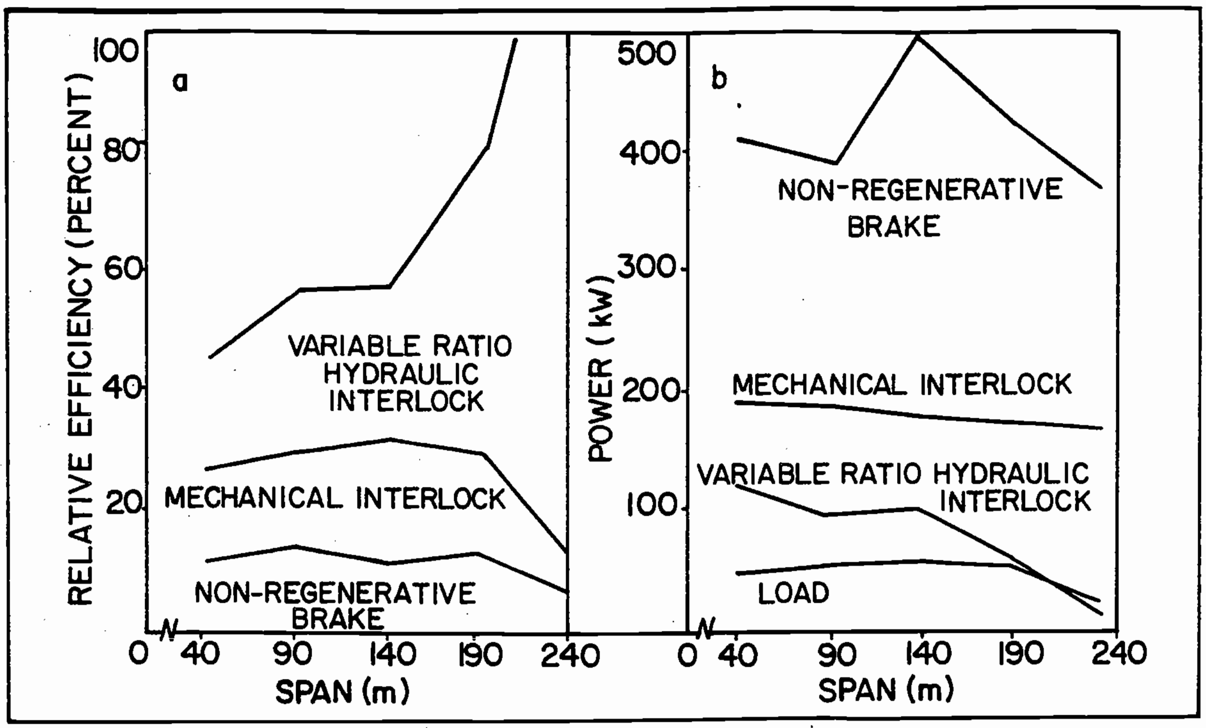

Figure 19(a) Relative efficiencies of three yarders. (b) Required power for each yarder to move the load at equal speed.

in combination with a 4-speed gearbox. The drop in relative efficiency shown for the mechanical yarder is attributable to low converter efficiency resulting from the low drum torque requirements of the relatively light load (5000 pounds) used in this example. The different torque converter and 4-speed transmission allows the variable ratio interlock machine to operate more efficiently over a wider range of loading conditions. The high relative efficiency near the tailhold demonstrates the capability of an interlock to utilize the potential energy given up by the log, thus reducing required input power. In fact, the engine may need to function as a brake in some cases.

This illustrates that two yarders which can support the same payload may have very different productive potential. Forest engineers can use the method of analysis presented here to verify that production estimates for a given yarder are reasonable.

Figure 20 shows the potential error involved when predicting payloads using design tensions unrelated to the tensioning capability of the yarder. If the safe working load (one-third of the breaking strength) of a 7/8 inch line were used as the limiting haulback tension for the mechanical interlock yarder, the payload capability would be overestimated by as much as 86%.

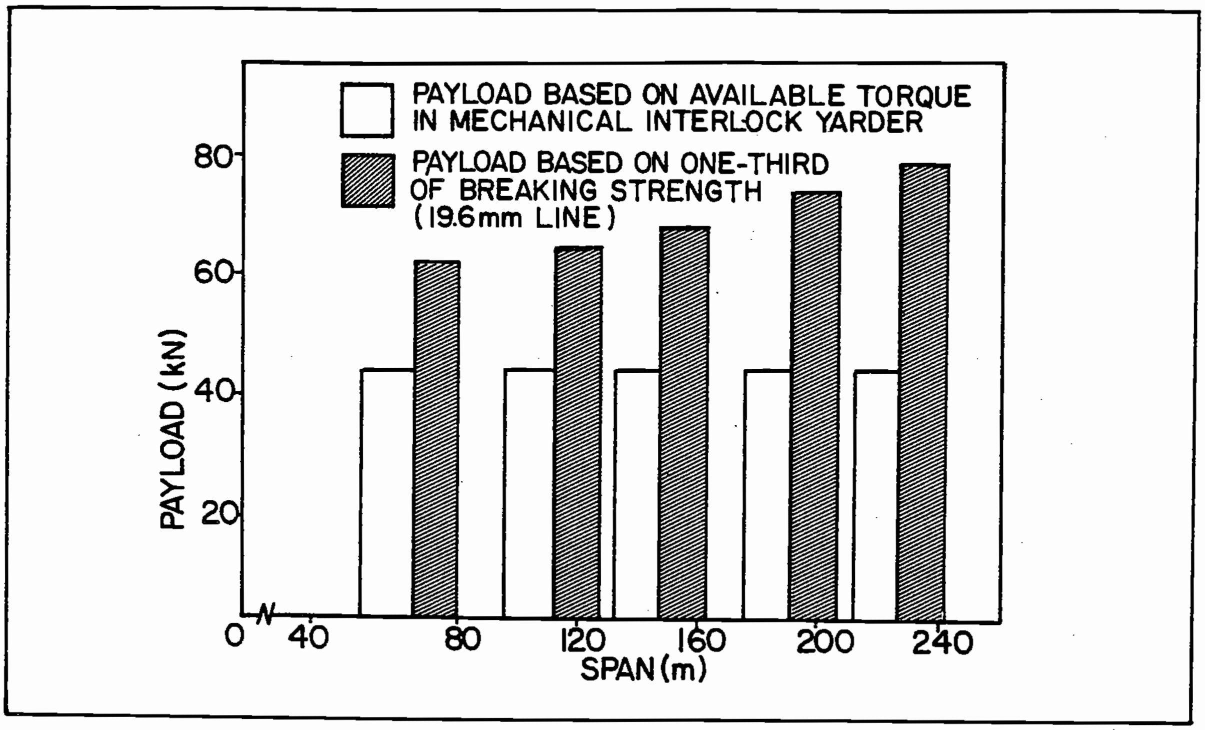

Figure 20. Payloads over the same profile predicted using a working tension of one-third of breaking strength, versus mechanical capability of the yarder.

VII. CONCLUSION

A systematic approach for determining running skyline performance based on the mechanical characteristics of the yarder has been developed. This approach can be applied to the three basic designs of running skyline machines. Computer code for implementing this procedure can be found in the Appendix. These programs can be integrated into existing skyline analysis software. Forest engineers should be able to utilize these algorithms in order to more accurately appraise the relative performance of different machines. This will assist in making decisions concerning equipment selection and sale layout.

VIII. SUGGESTIONS FOR FURTHER STUDY

Further development of the procedures presented in this paper is desirable:

1. Adaptation of the method to other systems such as live and standing skylines.
2. Addition of a slackpulling line.
3. Model development for downhill yarding.
4. Using catenary relationships to estimate line tensions and lengths.

The methods outlined in this paper would be readily adaptable to other systems. Power flow for live and standing skylines would be the same as that for the non-interlocked yarder. Many running skyline systems use slackpulling carriages. Addition of a slackpulling line would more accurately model these systems.

Addition of downhill yarding capability to the model is desirable since a significant proportion of running skyline settings fall into this category. Downhill yarding has been defined as any time the yarder engine must supply negative torque in order to control the load. To add downhill yarding to the model, closed throttle engine performance curves must be related to converter "braking" data so the engine-converter operating condition associated with the required braking torque can be determined. Finally, catenary relationships could be added in order to refine the estimation of line tensions. This would be particularly desirable when low interlock or brake pressures result in line tensions substantially below the safe working load of the line. Catenary analysis would increase computational time of the model.

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APPENDIX I

KEY TO SYMBOLS

KEY TO SYMBOLS

b_r	Empty drum radius.
C_h	Torque rating of motor
C_t	Torque rating of clutch or brake.
D	Log diameter.
D_p	Displacement of the hydraulic pump.
Dy	Current trial for deflection.
D_{yi}	Previous trial for deflection.
D_{ynew}	New trial for deflection.
d	Diameter of wire rope.
E	Over all efficiency (not including converter).
E_i	Interlock efficiency.
H_v	Haulback line speed.
K	Constant equal to .2618.
K_c	Converter capacity factor.
L	Length of line stored on drum.
L_l	Log length.
L_{srat}	Line speed ratio.
M	Torque delivered to drum.
M_c	Torque transferred across the interlock clutch.
M_e	Engine torque.
M_{hb}	Torque at haulback drum.
M_{hyd}	Torque at hydraulic motor.

M_{ml}	Torque at mainline drum.
M_{out}	Required converter out put torque.
M_p	Pump torque requirement.
M_v	Mainline speed.
n	Number of wraps of wire rope on drum.
n_e	Rotational speed of the engine.
n_h	Rotational speed of th haulback drum.
n_i	Rotational speed of the haulback or mainline drive pinion.
n_m	Rotational speed of the mainline drum.
n_{out}	Converter output speed.
p	Air pressure.
P_l	Power lost through the brake, clutch, or the hydrostatic drive.
P_m	Hydraulic motor power.
P_p	Hydraulic pump power.
R	Total speed reduction from converter output shaft to the mainline drum.
r_h	Effective radius of the haulback drum.
r_m	Effective radius of the mainline drum.
r_e	Drum effective radius.
Sr_c	Converter speed ratio.
T	Tension.
Tr_c	Calculated torque ratio (regression).
T_r	Actual torque ratio.
W	Current value for payload.
W_d	Drum width.

W_g Desired net payload.

W_o Previous value for payload.

α Tagline angle.

β Log to ground angle.

β_o Previous trial for log to ground angle.

ΔH_l Change in length of haulback.

Δn Differential speed or slip.

ΔM_l Change in length of mainline.

Δp Hydraulic pressure differential.

θ Ground slope angle.

APPENDIX II

EXAMPLES OF PROGRAM INPUT AND OUTPUT

and

COMPUTER CODES

EXAMPLE OF NON-INTERLOCKED RUNNING SKYLINE MODEL

INPUT

Profile:

TERRAIN POINT	X	Y	SLOPE DIST	% SLOPE
0	0.00	1000.00	0.00	0.00
1	136.79	938.45	150.00	-45.00
2	322.48	864.17	200.00	-40.00
3	461.76	808.46	150.00	-40.00
4	647.45	734.18	200.00	-40.00
5	786.72	678.47	150.00	-40.00
6	972.42	604.19	200.00	-40.00
7	986.58	599.24	15.00	-35.00
8	1086.58	599.24	100.00	0.00
9	1228.15	648.79	150.00	35.00
10	1369.73	698.34	150.00	35.00

Yarder:

EDCO Mustang III

Head spar/tailspar geometry:

YARDER IS LOCATED AT T.P.# 0

TAILHOLD IS 20 FEET HIGH AT T.P.# 10

External yarding limit:

Terrain point #6

Air pressure on haulback brake:

######## BRAKE PRESSURE HELD CONSTANT AT 65 PSI ########

Design payload:

PAYLOAD= 5000

OUTPUT

T.P.	MLT (LBS)	HBT (LBS)	REQUIRED H.P.	LSPD (FPM)	SUSPENSION	LOG CLEARANCE (FT)	BETA (DEG)
1	14597	12148	397	586	PART	24	48
2	13996	11503	396	609	PART	20	40
3	13282	10923	396	639	PART	21	41
4	12717	10923	396	658	PART	28	57
5	11628	10398	396	698	FULL	8	0
6	10827	9922	395	724	FULL	49	0

AVE. HORSE POWER DISSIPATED AT HAULBACK BRAKE=239.33

INDEX

Item	Line Numbers
"Dummy" terrain points	320-390
Yarder specifications	780-1020
Log drag parameters	1060-1140
Effective radius	1540-1570
Equation for engine torque	3310
Speed ratio (Sr) as a function of K_c	3550-3610
Torque ratio (Tr_c) as a function of Sr	3660-3710

All variables that are subscripted for retrieval from memory, are listed between lines 100 and 160. For internal calculations, the subscripts are twice the terrain point value. For example, the torque converter efficiency at terrain point #4 is designated as Tce(8).

```
10  !************************* NON-INTERLOCKED ******************************
20  !
30  ! USES MODIFIED SECANT SEARCH PROCEDURE TO FIND LOAD PATH
40  !
50  !
60  PRINT PAGE
70  !
80  INPUT "NAME OF PROFILE YOU WISH TO USE",F$     ! READS PROFILE DATA
90  DEG
100 DIM S(100),A(100),X(100),Y(100),Ss(100),Aa(100),Sclear(100),Beta(100)
110 DIM Dy(100),L3(100),Mrig(100),Hrig(100),Drt(100),Dlt(100),Skyl(100)
120 DIM Hre(100),Mre(100),Dratio(100),Hbt(100),Cl(100),Lsr(100),Ke(100)
130 DIM Erpm(100),Me(100),Mml(100),Mout(100),Tr(100),Trt(100),Sr(100)
140 DIM Mrpm(100),Hrpm(100),Mlspd(100),Pl(100),Tce(100),Wnet(100),Wv(100)
150 DIM Mlt(100),Theta(100),Lc(100),Ge(100),Alpha(100),Hpreq(100),Pml(100)
160 DIM Mltmax(100),Trc(100),Flc(100)
170 ASSIGN #1 TO "WILBANKS/"&F$
180 N=0
190 Nn=0
200 READ #1;X(0),Y(0)
210 FOR I=1 TO 100                            ! LOAD EVEN # PTS. INTO ARRAY
220   J=2*I                                    ! (ACTUAL TERRAIN POINTS)
230   READ #1;Ss(I),Aa(I)
240   IF ABS(Ss(I))+ABS(Aa(I))=0 THEN 320
250   A=ATN(Aa(I)/100)
260   X(J)=X(J-2)+Ss(I)*COS(A)
270   Y(J)=Y(J-2)+Ss(I)*SIN(A)
280   S(J)=Ss(I)
290   A(J)=Aa(I)
300   N=N+1
310 NEXT I
320 FOR I=0 TO N                              ! LOAD ODD # PTS. INTO ARRAY
330   J=2*I+1                                  !  (DUMMY TERRAIN POINTS)
340   X(J)=X(J-1)+.01*(X(J+1)-X(J-1))
350   Y(J)=Y(J-1)+.01*(Y(J+1)-Y(J-1))
360   S(J)=.01*Ss(I+1)
370   A(J)=Aa(I+1)
380   Nn=Nn+1
390 NEXT I
400 N=N+Nn-1
410 ASSIGN #1 TO *
420 PRINT "WILBANKS/"&F$
430 PRINT
440 S(0)=0
450 A(0)=0
460 PRINT "TERRAIN POINT        X          Y         SLOPE DIST    % SLOPE"
470 !
480 FOR I=0 TO N STEP 2                       ! PRINTS PROFILE DATA
490   Tp=I/2
500   PRINT USING 510;Tp,X(I),Y(I),S(I),A(I)
510   IMAGE 4X,4D,9X,5D.2D,2X,5D.2D,4X,5D.2D,4X,5D.2D
520 NEXT I
530 PRINT
540 INPUT "YARDER LOCATION ?",Tp1
550 INPUT "LOCATION OF TAILHOLD AND HEIGHT ?",Tp2,Hh2
560 IF Tp2>Tp THEN
570   BEEP
580   DISP "TAILHOLD MUST BE BETWEEN 0 AND";Tp;"  PRESS CONT WHEN READY"
590   PAUSE
600   GOTO 540
```

```
610  END IF
620  PRINT USING 630;Tp1
630  IMAGE "YARDER IS LOCATED AT T.P.#",3D
640  PRINT
650  PRINT USING 660;Hh2,Tp2
660  IMAGE "TAILHOLD IS",3D,X,"FEET HIGH AT T.P.#",3D
670  PRINT
680  Tp1=2*Tp1
690  Tp2=2*Tp2
700  INPUT "EXTERNAL YARDING LIMIT ?",Eyd
710  Eyd=Eyd*2
720  IF Eyd=Tp2 THEN Eyd=Eyd-2
730  !
740  !******************** RUNNING SKYLINE ANALYSIS  ************************
750  !
760  INPUT "WEIGHT OF TURN TO BE YARDED (LBS)?",Wg
770  !
780  !************** YARDER SPECS. BASED ON EDCO MUSTANG III ****************
790  !
800  Rmain=.0698                          ! REDUCTION : TRANS TO ML DRUM
810  Egear=.8                             ! OVERALL MECHANICAL EFFICIENCY
820  Mbr=7                                ! MAINLINE BARREL RADIUS
830  Mbw=24                               !   "       "    WIDTH
840  Mlc=2700                             !   "     DRUM CAPACITY
850  Hbr=7                                ! HAULBACK BARREL RADIUS
860  Hbw=24                               !   "       "    WIDTH
870  Hlc=4200                             !   "     DRUM CAPACITY
880  Tower=50                             ! TOWER HEIGHT
890  Hh1=Tower
900  !*********************************************************************
910  !
920  INPUT "PRESSURE SETTING ON HAULBACK BRAKE (PSI)?",Psi
930  PRINT "######## BRAKE PRESSURE HELD CONSTANT AT";Psi;"PSI ########"
940  PRINT
950  PRINT "PAYLOAD=";Wg
960  PRINT
970  M=Psi*208.3                         ! TORQUE AVAILABLE AT HAULBACK DRUM
980  Diam=7/8                            ! DIA. MAINLINE
990  Diah=3/4                            ! DIA. HAULBACK
1000 W1=1.04                             ! WEIGHT/FOOT OF HAULBACK
1010 W3=1.42                             ! WEIGHT/FOOT OF MAINLINE
1020 Wc=600                              ! CARRIAGE WEIGHT
1030 Count=0
1040 J=0
1050 !
1060 !********************** LOG DRAG PARAMETERS ****************************
1070 !
1080 Ll=32                               ! LOG LENGTH
1090 Hc=3                                ! CARRIAGE HEIGHT
1100 U=.6                                ! COEFFICIENT OF FRICTION
1110 Choke=24                            ! CHOKER LENGTH
1120 Logdia=2                            ! LOG DIAMETER (FEET)
1130 Ce=Choke-PI*Logdia                  ! EFFECTIVE CHOKER LENGTH
1140 Fly=Ll+Ce+Hc                        ! REQ. CLEARANCE TO FLY
1150 !
1160 !*********************************************************************
1170 !
1180 IF Tp1=0 THEN
1190   First=2
1200 ELSE
1210   First=Tp1+1
1220 END IF
1230 FOR I=First TO Eyd
```

```
1240  !************************ FIND LOAD PATH ********************************
1250  !
1260    Drag=0
1270    G=0                          ! COUNTER FOR Dy ITERATION
1280    Sclear(I)=0
1290    Beta(I)=0
1300    IF .01*A(I)>U THEN           ! TEST FOR SLOPE GREATER THAN
1310      Slide=1                    ! COEFFICIENT OF FRICTION
1320    ELSE
1330      Slide=0
1340    END IF
1350    IF Drag>0 THEN
1360      GOSUB 4430
1370    ELSE
1380      GOSUB 4190
1390    END IF
1400  !
1410  !********************* CALCULATE LINE LENGTHS **************************
1420  !
1430    Hrt=Dy(I)-Lh
1440    L3(I)=SQR(Dlt(I)^2+Dy(I)^2)
1450    Mrig(I)=L3(I)+Tower                                ! MAINLINE OUT
1460    Hrig(I)=L3(I)+2*SQR(Drt(I)^2+Hrt^2)+Tower          ! HAULBACK OUT
1470    Skyl(I)=Mrig(I)+Hrig(I)
1480    Ml=Mlc-Mrig(I)                                     ! MAINLINE ON DRUM
1490    Hl=Hlc-Hrig(I)                                     ! HAULBACK ON DRUM
1500    K=.2618
1510  !
1520  !*********************** CALC. WORKING HB TEN.**************************
1530  !
1540    Hn=INT((-Hbr+(Hbr^2+(Diah^2*Hl/(K*Hbw)))^.5)/Diah)+1
1550    Mn=INT((-Mbr+(Mbr^2+(Diam^2*Ml/(K*Mbw)))^.5)/Diam)+1
1560    Hre(I)=Hbr+(Hn-.5)*Diah
1570    Mre(I)=Mbr+(Mn-.5)*Diam
1580    IF G=1 THEN
1590      Hbt(I)=M/(Hre(I)/12)                        ! HAULBACK TENSION
1600      Mltmax(I)=27150/(Mre(I)/12)                 ! MAX MAINLINE TEN. AS
1610    END IF                                        ! LIMITED BY PULLING CLUTCH
1620    IF Drag=1 THEN
1630      Hbt(I)=M/(Hre(I)/12)
1640      Mltmax(I)=27150/(Mre(I)/12)
1650    END IF
1660    IF Slide=2 THEN
1670      Hbt(I)=M/(Hre(I)/12)
1680      Mltmax(I)=27150/(Mre(I)/12)
1690    END IF
1700  !
1710  !************************ COMPUTE SEGMENT FORCES ***********************
1720  !
1730  !
1740  !**************************** SKYLINE LEFT *****************************
1750  !
1760    Tu=Hbt(I)                                     ! TENSION AT YARDER
1770    D=Dlt(I)
1780    Hh=Dy(I)
1790    Ww=W1
1800    GOSUB 5910
1810    V1=Vl
1820    H1=H
1830    !
1840    !
```

```
1850    !******************** SKYLINE RIGHT ************************
1860    !
1870    IF Hrt>0 THEN
1880      Tu=Hbt(I)-W1*Lh                          ! TU @ TAILSPAR
1890      Hh=Hrt
1900    ELSE
1910      Tu=Hbt(I)-W1*Dy(I)                       ! TU @ CARRIAGE
1920      Hh=-Hrt
1930    END IF
1940    D=Drt(I)
1950    Ww=W1
1960    GOSUB 5910
1970    H2=H
1980    IF Hrt>0 THEN V2=V1
1990    IF Hrt<0 THEN V2=-(V1+W1*L)
2000    !
2010    !************************* HAULBACK *********************************
2020    !
2030    IF Hrt>0 THEN
2040      Tu=Hbt(I)-W1*Lh                          !TU @ TAILSPAR
2050      Hh=Hrt
2060    ELSE
2070      Tu=Hbt(I)-W1*Dy(I)                       ! TU @ CARRIAGE
2080      Hh=-Hrt
2090    END IF
2100    D=Drt(I)
2110    Ww=W1
2120    GOSUB 5910
2130    H4=H
2140    IF Hrt>0 THEN V4=V1
2150    IF Hrt<0 THEN V4=-(V1+W1*L)
2160    !
2170    !****************** PAYLOAD AND MAINLINE TENSION ********************
2180    IF Drag>0 THEN
2190      GOSUB 3900                               ! DRAGGING
2200    ELSE
2210      GOSUB 4050                               ! FLYING
2220    END IF
2230    !*********************************************************************
2240    IF Drag>0 THEN
2250      IF ABS(Z)<.02*Wg THEN
2260        IF Hl>=50 THEN                         ! TEST FOR SUFFICIENT
2270          Mml(I)=Mlt(I)*(Mre(I)/12)            ! HAULBACK LENGTH
2280          !
2290          IF Mml(I)<27150 THEN                 ! TEST FOR CLUTCH LIMITING
2300            GOTO 2510
2310          ELSE
2320            DISP "MAINLINE DRUM CLUTCH IS LIMITING AT TERRAIN POINT #";I/2
2330            WAIT 4
2340            GOTO 2510
2350          END IF
2360        ELSE
2370          DISP "HAULBACK LENGTH EXCEEDED,TRY AGAIN"
2380          WAIT 4
2390          GOTO 760
2400        END IF
2410      END IF
2420    ELSE
2430      IF ABS(Z)<.02*Wg THEN 2470
2440    END IF
```

```
2450   GOTO 1350
2460   !
2470   IF Cl(I)<Fly THEN                            ! TEST FOR FULL SUSPENSION
2480     Drag=1
2490     GOTO 1350
2500   END IF
2510 NEXT I
2520 !
2530 !*********************** CALC. POWER BALANCE *************************
2540 !
2550 FOR I=Tp1+2 TO Eyd STEP 2
2560 T=0
2570 Et=0
2580 IF Et>0 THEN
2590   GOSUB 3350                                 ! ITERATE FOR THROTTLE SETTING
2600   GOSUB 3530                                 ! CALC SPEED RATIO
2610   GOSUB 3650                                 ! CALC CONVERTER TORQUE RATIO
2620   GOSUB 3750                                 ! CALC ACTUAL TORQUE RATIO
2630 ELSE
2640   GOSUB 3160                                 ! ITERATE FOR ENGINE SPEED
2650   GOSUB 3530                                 ! CALC SPEED RATIO
2660   GOSUB 3650                                 ! CALC CONVERTER TORQUE RATIO
2670   GOSUB 3750                                 ! CALC ACTUAL TORQUE RATIO
2680 END IF
2690 IF Mout(I)<0 THEN  GOTO 2990                 ! TEST FOR NEGATIVE OUTPUT TORQUE
2700 Zt=Tr(I)-Trc(I)
2710 IF Et=0 THEN                                 ! FIRST ITERATION OF ENGINE SPEED
2720   IF T=0 THEN                                ! ROUTINE (GOV SPD), MUST REDUCE
2730     IF Zt<0 THEN                             ! THROTTLE SETTING IF Zt IS NEG.
2740       Et=1
2750       GOTO 2580
2760     END IF
2770   END IF
2780 END IF
2790 IF ABS(Zt)<.001 THEN                    ! IS OPERATING COND. ERROR ACCEPTABLE?
2800   IF Ke(I)>=49.86 THEN                  ! IS OPERATING COND. FEASIBLE?
2810     IF Erpm(I)>2100 THEN
2820       Et=1
2830       GOTO 2580
2840     END IF
2850   ELSE
2860     PRINT "INFEASIBLE LOAD AT TP#";I/2
2870     GOTO 2580
2880   END IF
2890 ELSE
2900   T=T+1
2910   GOTO 2580
2920 END IF
2930 Mrpm(I)=Sr(I)*Erpm(I)*Rmain                   ! MAIN DRUM RPM
2940 Mlspd(I)=Mrpm(I)*(Mre(I)/12)*2*PI              ! MAINLINE SPEED
2950 Pml(I)=Mml(I)*Mrpm(I)/5252                     ! POWER IN MAINLINE
2960 GOSUB 3820                                     ! CALC POWER LOST AT HB BRAKE
2970 GOSUB 5800                                     ! CALC AVE POWER LOST AT BRAKE
2980 Hpreq(I)=Me(I)*Erpm(I)/5252                    ! REQUIRED HORSE POWER
2990 NEXT I
3000 !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
3010 GOSUB 5420                                    ! PRINT OUTPUT
3020 INPUT "DO YOU WISH TO CHANGE YARDER LOCATION OR TAILHOLD GEOMETRY ?",T$
3030 IF T$="NO" THEN 3120
3040 INPUT "NEW YARDER LOCATION ?",Tp1
3050 INPUT "NEW LOCATION OF TAILHOLD AND HEIGHT ?",Tp2,Hh2
```

```
3060 PRINT USING 630;Tp1
3070 PRINT
3080 PRINT USING 660;Hh2,Tp2
3090 PRINT
3100 Tp1=2*Tp1
3110 Tp2=2*Tp2
3120 Brake=0
3130 GOTO 760
3140 END       !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
3150 !
3160 !-------------------- SUBROUTINE VARIES ENGINE SPEED --------------------
3170 !
3180 IF T=0 THEN Erpm(I)=2100            ! TRIAL ENGINE SPEED (GOV SPEED)
3190 IF T=1 THEN
3200   Erpm(I)=1400
3210   Delta=200
3220 END IF
3230 IF T>1 THEN
3240   IF Zt<0 THEN
3250     Erpm(I)=Erpm(I)+Delta            ! INCREASE RPM IF NEED LESS TORQUE
3260   ELSE
3270     Erpm(I)=Erpm(I)-Delta/2          ! DECREASE RPM IF NEED MORE TORQUE
3280     Delta=Delta/2
3290   END IF
3300 END IF
3310 Me(I)=2219.12-.59*Erpm(I)           ! CALC. ENGINE TORQUE AS FCN. OF RPM
3320 Ke(I)=Erpm(I)/SQR(Me(I))            ! CALC. CAPACITY FACTOR
3330 RETURN
3340 !
3350 !----------------- SUBROUTINE VARIES THROTTLE SETTING ------------------
3360 !
3370 IF Et=1 THEN
3380   Erpm(I)=2100                       ! SET ENGINE AT GOVERNED SPEED
3390   Ke(I)=49.86
3400   Delta=10
3410   Et=Et+1
3420 ELSE
3430   IF Zt<0 THEN
3440     Ke(I)=Ke(I)+Delta                ! INCREASE Ke IF NEED LESS TORQUE
3450   ELSE
3460     Ke(I)=Ke(I)-Delta/2              ! DECREASE Ke IF NEED MORE TORQUE
3470     Delta=Delta/2
3480   END IF
3490 END IF
3500 Me(I)=Erpm(I)^2/Ke(I)^2             ! CALC. ENGINE TORQUE AS FCN . OF
3510 RETURN                              ! THROTTLE SETTING
3520 !
3530 !------------------ SUBROUTINE CALCULATES SPEED RATIO ------------------
3540 !
3550 IF Ke(I)<52.9 THEN Sr(I)=(Ke(I)-49.86)*.050775   ! TD-11500-MS-340
3560 IF Ke(I)>=52.9 THEN
3570   IF Ke(I)<=63.38 THEN
3580     Sr(I)=.00010*EXP(.13956*Ke(I))
3590   ELSE
3600     Sr(I)=.01534*EXP(.06060*Ke(I))
3610   END IF
3620 END IF
3630 RETURN
3640 !
3650 !------------ SUBROUTINE CALCULATES CONVERTER TORQUE RATIO -------------
3660 !
```

```
3670  IF Sr(I)<=.709 THEN
3680    Trc(I)=5.0812*EXP(-2.2878*Sr(I))
3690  ELSE
3700    Trc(I)=-.11566-3.35498*LOG(Sr(I))
3710  END IF
3720  Tce(I)=Trc(I)*Sr(I)                  ! CALC. CONVERTER EFFICIENCY
3730  RETURN
3740  !
3750  !-------------- SUBROUTINE CALCULATES ACTUAL TORQUE RATIO --------------
3760  !
3770  Mml(I)=Mlt(I)*(Mre(I)/12)             ! TORQUE REQ. @ MAIN DRUM
3780  Mout(I)=Mml(I)*Rmain/Egear            ! TORQUE REQ. @ OUTPUT SHAFT
3790  Tr(I)=Mout(I)/Me(I)                   ! ACTUAL TORQUE RATIO
3800  RETURN
3810  !
3820  !**************** CALCULATE ANGULAR VELOCITY OF HAULBACK ***************
3830  !
3840  Dratio(I)=Mre(I)/Hre(I)               ! DRUM RADIUS RATIO
3850  Lsr(I)=ABS((Hrig(I+1)-Hrig(I))/(Mrig(I+1)-Mrig(I))) ! LINE SPEED RATIO
3860  Hrpm(I)=Mrpm(I)*Dratio(I)*Lsr(I)      ! HAULBACK RPM
3870  Pl(I)=M*Hrpm(I)/5252                  ! POWER DISSIPATED AT HB BRAKE
3880  RETURN
3890  !
3900  !^^^^^^^^^^^^^^^^^^^^ COMPUTE NET PAYLOAD DRAGGING ^^^^^^^^^^^^^^^^^^^^
3910  !
3920  Wnet=((Dy(I)/Dlt(I))*(H4+H2-H1)-.5*W3*L3(I)-Wc+V1+V2+V4)/(N1-N2*Dy(I)/Dl
t(I))
3930  Wv(I)=Wnet*N1
3940  Wh=Wnet*N2
3950  !
3960  !^^^^^^^^^^^^^^^^^^^ CALC DRAGGING MAINLINE TENSION ^^^^^^^^^^^^^^^^^^^
3970  !
3980  H3=H2+H4-H1+Wh
3990  V3=Wv(I)+Wc-V1-V2-V4
4000  Mlt(I)=SQR(H3^2+V3^2)+W3*Dy(I)               ! MAINLINE TENSION
4010  Z=Wnet-Wg                                    ! DRAGGING PAYLOAD ERROR
4020  Sclear(I)=Cc+Hc-Xp*TAN(Theta(I))             ! DRAGGING SKYLINE CLEARANCE
4030  RETURN
4040  !
4050  !***************** CALC SUSPENDED MAINLINE TENSION *********************
4060  !
4070  H3=H2+H4-H1
4080  V3=H3*Dy(I)/Dlt(I)-.5*W3*L3(I)
4090  Mlt(I)=SQR(H3^2+(V3+W3*L3(I))^2)
4100  !
4110  !****************** COMPUTE NET PAYLOAD SUSPENDED **********************
4120  !
4130  W=V1+V2+V3+V4-Wc                            ! NET PAYLOAD
4140  IF G=0 THEN Wo=W
4150  Cl(I)=Y(Tp1)+Hh1-Dy(I)-Y(I)                 ! CALC SKYLINE CLEARANCE
4160  Flc(I)=Cl(I)-Fly                            ! CALC SUSPENDED LOG CLEARANCE
4170  Z=W-Wg                                      ! SUSPENDED PAYLOAD ERROR
4180  RETURN
4190  !@@@@@@@@@@@@ SUBROUTINE FOR FULLY SUSPENDED DEFLECTION @@@@@@@@@@@@@@@@
4200  !
4210  Dlt(I)=X(I)-X(Tp1)                          ! SEGMENT GEOMETRY
4220  Drt(I)=X(Tp2)-X(I)
4230  Span=Drt(I)+Dlt(I)
4240  Lh=((Y(Tp1)+Hh1)-(Y(Tp2)+Hh2))
4250  IF G=0 THEN
4260    Dvi=Dlt(I)*Lh/Span                        ! 1st GUESS FOR DEFLECTION
```

```
4270     Dy(I)=Dyi
4280   END IF
4290   IF G=1 THEN
4300     Dy(I)=Dyi+Span/100                      ! 2nd GUESS FOR DEFLECTION
4310     Wo=W
4320   END IF
4330   IF G>1 THEN
4340     Slope=(W-Wo)/(Dy(I)-Dyi)
4350     Wo=W
4360     Dyi=Dy(I)
4370     Dy(I)=(Wg-Wo)/Slope+Dyi                 ! NEW GUESS FOR DEFLECTION
4380   END IF
4390   G=G+1
4400   RETURN
4410   !@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
4420   !
4430   !################ SUBROUTINE FOR DRAGGING DEFLECTION #################
4440   !
4450   Flc(I)=0
4460   Theta(I)=-ATN(.01*A(I))                   ! GROUND ANGLE
4470   !
4480   !******************** LOG TO GROUND ANGLE (BETA) ***********************
4490   !
4500   IF Slide>0 THEN 4840
4510   IF Drag=1 THEN                            ! CONDITION 1&2
4520   !
4530     Betao=ASN(Logdia/L1)+5                  ! 1st GUESS FOR BETA
4540     Lay=Betao                               !  (LOWER LIMIT)
4550     Beta(I)=Betao
4560   END IF
4570   IF Drag=2 THEN
4580     Beta(I)=89-Theta(I)                     ! 2nd GUESS FOR BETA
4590     Hang=Beta(I)                            !  (UPPER LIMIT)
4600     Wo=Wnet
4610   END IF
4620   IF Drag>2 THEN
4630     Slope=(Wnet-Wo)/(Beta(I)-Betao)
4640     Wo=Wnet
4650     Betao=Beta(I)
4660     Step=(Wg-Wo)/Slope
4670     Beta(I)=Step+Betao                      ! NEW GUESS FOR BETA
4680     IF Beta(I)>Hang THEN
4690       Step=Step/2
4700       GOTO 4670
4710     END IF                                  ! KEEP SEARCH WITHIN
4720     IF Beta(I)<Lay THEN                     ! UPPER AND LOWER BOUNDS
4730       Step=Step/2
4740       GOTO 4670
4750     END IF
4760     IF Beta(I)<Lay+.1 THEN                  ! CHECK FOR SUFFICIENT
4770       IF Betao<Lay+.1 THEN                  ! TENSION/DEFLECTION
4780         DISP "INSUFFICIENT DEFLECTION AT TP#";I/2
4790         WAIT 4
4800         GOTO 760
4810       END IF
4820     END IF
4830   END IF
4840   IF Slide=1 THEN                           ! CONDITION 3 (LOG SLIDES)
4850     Betao=180                               ! 1st GUESS FOR BETA
4860     Lay=Betao                               !  (UPPER LIMIT)
```

```
4870    Beta(I)=Betao
4880  END IF
4890  IF Slide=2 THEN
4900    Beta(I)=89-Theta(I)                        ! 2nd GUESS FOR BETA
4910    Hang=Beta(I)                               !  (LOWER LIMIT)
4920    Wo=Wnet
4930  END IF
4940  IF Slide>2 THEN
4950    Slope=(Wnet-Wo)/(Beta(I)-Betao)
4960    Wo=Wnet
4970    Betao=Beta(I)
4980    Step=(Wg-Wo)/Slope
4990    Beta(I)=Step+Betao                         ! NEW GUESS FOR BETA
5000    IF Beta(I)<Hang THEN
5010      Step=Step/2
5020      GOTO 4990
5030    END IF
5040    IF Beta(I)>Lay THEN                        ! KEEP SEARCH WITHIN
5050      Step=Step/2                              ! UPPER AND LOWER BOUNDS
5060      GOTO 4990
5070    END IF
5080    IF Beta(I)>179.9 THEN                      ! CHECK FOR SUFFICIENT
5090      IF Betao>179.9 THEN                      ! TENSION/DEFLECTION
5100        DISP "INSUFFICIENT HAULBACK TENSION AT TP#";I/2
5110        WAIT 4
5120        GOTO 760
5130      END IF
5140    END IF
5150  END IF
5160  !
5170  !************************** TAGLINE ANGLE ******************************
5180  !
5190  Kk=2*(1+U*TAN(Beta(I)))
5200  N1=1-(COS(Theta(I))-SIN(Theta(I))*TAN(Beta(I)))*(COS(Theta(I))-U*SIN(The
ta(I)))/Kk
5210  N2=(COS(Theta(I))-SIN(Theta(I))*TAN(Beta(I)))*(SIN(Theta(I))+U*COS(Theta
(I)))/Kk
5220  Alpha=ATN(N2/N1)
5230  !
5240  Ga=Beta(I)+Theta(I)-ATN(Logdia/L1)
5250  Lc(I)=L1*SIN(Ga)-(L1*COS(Ga)*TAN(Theta(I)))   ! CALC LOG END CLEARANCE
5260                                                 !     (VERTICAL)
5270  !
5280  !********************* COMPUTE SEGMENT GEOMETRY ************************
5290  !
5300  Xp=L1*COS(Beta(I)+Theta(I))+Ce*SIN(Alpha)
5310  Cc=L1*SIN(Beta(I)+Theta(I))+Ce*COS(Alpha)
5320  Dlt(I)=X(I)-X(Tp1)-Xp
5330  Drt(I)=X(Tp2)-X(I)+Xp
5340  Span=Drt(I)+Dlt(I)
5350  Lh=((Y(Tp1)+Hh1)-(Y(Tp2)+Hh2))
5360  Dy(I)=Y(Tp1)+Hh1-Cc-Hc-Y(I)                    ! DEFLECTION
5370  Drag=Drag+1
5380  IF Slide>0 THEN Slide=Slide+1
5390  RETURN
5400  !######################################################################
5410  !
```

```
5420  !************************** PRINT OUTPUT ********************************
5430  !
5440  PRINT
5450  PRINT
5460  PRINT "T.P.     MLT       HBT    REQUIRED   LSPD   SUSPENSION   LOG CLE
ARANCE   BETA"
5470  PRINT "         (LBS)      (LBS)     H.P.     (FPM)                       (
FT)   (DEG)  "
5480  PRINT
5490  FOR I=Tp1+2 TO Eyd STEP 2
5500    Tp=I/2
5510    IF Mout(I)>0 THEN
5520      IF Flc(I)>0 THEN
5530        PRINT USING 5650;Tp,Mlt(I),Hbt(I),Hpreq(I),Mlspd(I),Flc(I),Beta(I)
5540      ELSE
5550        PRINT USING 5660;Tp,Mlt(I),Hbt(I),Hpreq(I),Mlspd(I),Lc(I),Beta(I)
5560      END IF
5570    ELSE
5580      IF Flc(I)>0 THEN
5590        PRINT USING 5670;Tp,Mlt(I),Hbt(I),Hpreq(I),Mlspd(I),Flc(I),Beta(I)
5600      ELSE
5610        PRINT USING 5680;Tp,Mlt(I),Hbt(I),Hpreq(I),Mlspd(I),Lc(I),Beta(I)
5620      END IF
5630      Brake=1
5640    END IF
5650    IMAGE 3D,5X,5D,6X,5D,5X,4D,6X,4D,5X,"FULL",11X,3D,8X,3D
5660    IMAGE 3D,5X,5D,6X,5D,5X,4D,6X,4D,5X,"PART",11X,3D,8X,3D
5670    IMAGE 3D,5X,5D,6X,5D,5X,"   *   ",6X,"*     ","FULL",11X,3D,8X,3D
5680    IMAGE 3D,5X,5D,6X,5D,5X,"   *   ",6X,"*     ","PART",11X,3D,8X,3D
5690  NEXT I
5700  IF Brake=1 THEN
5710    PRINT
5720    PRINT "* NEGATIVE ENGINE TORQUE REQUIRED,SPEED INFORMATION NOT AVAILAB
LE"
5730  END IF
5740  PRINT
5750  PRINT USING 5760;Apl
5760  IMAGE "AVE. HORSE POWER DISSIPATED AT HAULBACK BRAKE=",3D.2D
5770  PRINT
5780  RETURN
5790  !
5800  !***************** SUBROUTINE FOR AVE. HP DISSAPATION ******************
5810  !
5820  J=J+1
5830  IF J=1 THEN
5840    Tpl=Pl(I)
5850  ELSE
5860    Tpl=Pl(I)+Tpl
5870  END IF
5880  Apl=Tpl/J
5890  RETURN
5900  !
5910  !************* SUBROUTINE FOR H,V (RIGID LINK MOMENT ARMS) *************
5920  !
5930  L=SQR(D^2+Hh^2)
5940  H=Tu*D/L*SQR(1-(.5*Ww*D/Tu)^2)-.5*Ww*D*Hh/L
5950  Vl=H*Hh/D-.5*Ww*L
5960  RETURN
```

EXAMPLE OF MECHANICAL INTERLOCK RUNNING SKYLINE MODEL

INPUT

Profile:

TERRAIN POINT	X	Y	SLOPE DIST	% SLOPE
0	0.00	1000.00	0.00	0.00
1	136.79	938.45	150.00	-45.00
2	322.48	864.17	200.00	-40.00
3	461.76	808.46	150.00	-40.00
4	647.45	734.18	200.00	-40.00
5	786.72	678.47	150.00	-40.00
6	972.42	604.19	200.00	-40.00
7	986.58	599.24	15.00	-35.00
8	1086.58	599.24	100.00	0.00
9	1228.15	648.79	150.00	35.00
10	1369.73	698.34	150.00	35.00

Yarder:

PSY 200 (original model)

Head spar/tailspar geometry:

YARDER IS LOCATED AT T.P.# 0

TAILHOLD IS 20 FEET HIGH AT T.P.# 10

External yarding limit:

Terrain point #6

Air pressure on interlock clutch:

######## INTERLOCK PRESSURE HELD CONSTANT AT 75 PSI ########

Design payload:

PAYLOAD= 5000

OUTPUT

T.P.	MLT (LBS)	HBT (LBS)	REQUIRED H.P.	LSPD (FPM)	SUSPENSION	LOG CLEARANCE (FT)	BETA (DEG)
1	14382	11803	414	1181	PART	22	43
2	14357	11803	417	1222	PART	19	36
3	13720	11285	420	1252	PART	18	36
4	13140	11285	411	1257	PART	26	53
5	11944	10811	397	1291	FULL	3	0
6	11601	10811	386	1246	FULL	52	0

AVE. HORSE POWER DISSIPATED AT INTERLOCK CLUTCH=144.13

INDEX

All variables that are subscripted for retrieval from memory, are listed between lines 120 and 180. For internal calculations, the subscripts are twice the terrain point value. For example, the torque converter efficiency at terrain point #4 is designated as Tce(8).

```
10   !********************* MECHANICAL INTERLOCK ***************************
20   !
30   ! USES MODIFIED SECANT SEARCH PROCEDURE TO FIND LOAD PATH
40   !
50   !
60   !@@@@@@@@@@@@@@@@@@@@@@@ BASED ON PSY-200 @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
70   !
80   PRINT PAGE
90   !
100  INPUT "NAME OF PROFILE YOU WISH TO USE",F$     ! READS PROFILE DATA
110  DEG
120  DIM S(100),A(100),X(100),Y(100),Ss(100),Aa(100),Sclear(100),Beta(100)
130  DIM Dy(100),L3(100),Mrig(100),Hrig(100),Drt(100),Dlt(100),Skyl(100)
140  DIM Hre(100),Mre(100),Dratio(100),Hbt(100),Cl(100),Lsr(100),Ke(100)
150  DIM Erpm(100),Me(100),Mml(100),Mout(100),Tr(100),Trt(100),Src(100)
160  DIM Mrpm(100),Hrpm(100),Mlspd(100),Pl(100),Tce(100),Wnet(100),Wv(100)
170  DIM Mlt(100),Theta(100),Lc(100),Ge(100),Alpha(100),Hpreq(100),Pml(100)
180  DIM Mltmax(100),Trc(100),Dn(100),Hbspd(100),Phb(100),Re(100),Flc(100)
190  ASSIGN #1 TO "WILBANKS/"&F$
200  N=0
210  Nn=0
220  READ #1;X(0),Y(0)
230  FOR I=1 TO 100                              ! LOAD EVEN # PTS. INTO ARRAY
240    J=2*I                                       !  (ACTUAL TERRAIN POINTS)
250    READ #1;Ss(I),Aa(I)
260    IF ABS(Ss(I))+ABS(Aa(I))=0 THEN 340
270    A=ATN(Aa(I)/100)
280    X(J)=X(J-2)+Ss(I)*COS(A)
290    Y(J)=Y(J-2)+Ss(I)*SIN(A)
300    S(J)=Ss(I)
310    A(J)=Aa(I)
320    N=N+1
330  NEXT I
340  FOR I=0 TO N                                ! LOAD OD # PTS. INTO ARRAY
350    J=2*I+1                                     !  (DUMMY TERRAIN POINTS)
360    X(J)=X(J-1)+.01*(X(J+1)-X(J-1))
370    Y(J)=Y(J-1)+.01*(Y(J+1)-Y(J-1))
380    S(J)=.01*Ss(I+1)
390    A(J)=Aa(I+1)
400    Nn=Nn+1
410  NEXT I
420  N=N+Nn-1
430  ASSIGN #1 TO *
440  PRINT "WILBANKS/"&F$
450  PRINT
460  S(0)=0
470  A(0)=0
480  PRINT "TERRAIN POINT        X          Y         SLOPE DIST    % SLOPE"
490  !
500  FOR I=0 TO N STEP 2                         ! PRINTS PROFILE DATA
510    Tp=I/2
520    PRINT USING 530;Tp,X(I),Y(I),S(I),A(I)
530    IMAGE 4X,4D,9X,5D.2D,2X,5D.2D,4X,5D.2D,4X,5D.2D
540  NEXT I
550  PRINT
560  INPUT "YARDER LOCATION ?",Tp1
570  INPUT "LOCATION OF TAILHOLD AND HEIGHT ?",Tp2,Hh2
580  IF Tp2>Tp THEN
590     BEEP
600     DISP "TAILHOLD MUST BE BETWEEN 0 AND";Tp;"  PRESS CONT WHEN READY"
```

```
610      PAUSE
620      GOTO 570
630   END IF
640   PRINT USING 650;Tp1
650   IMAGE "YARDER IS LOCATED AT T.P.#",3D
660   PRINT
670   PRINT USING 680;Hh2,Tp2
680   IMAGE "TAILHOLD IS",3D,X,"FEET HIGH AT T.P.#",3D
690   PRINT
700   Tp1=2*Tp1
710   Tp2=2*Tp2
720   INPUT "EXTERNAL YARDING LIMIT ?",Eyd
730   Eyd=Eyd*2
740   IF Eyd=Tp2 THEN Eyd=Eyd-2
750   !
760   !******************** RUNNING SKYLINE ANALYSIS  ************************
770   !
780   INPUT "WEIGHT OF TURN TO BE YARDED (LBS)?",Wg
790   !
800   !***************** YARDER SPECS. BASED ON PSY 200 **********************
810   !
820   Rmain=.07146                        ! REDUCTION : TRANS TO ML DRUM
830   Hinp=.2456                          ! REDUCTION : HB GEAR/INT. SHAFT
840   Minp=.3111                          ! REDUCTION : MAIN GEAR/INT. SHAFT
850   Rinp=Hinp/Minp                      ! SPEED RATIO : HB TO ML
860   Gear(1)=.976
870   Gear(2)=1.964
880   Egear=.8                            ! OVERALL EFICIENCY
890   Mbr=15                              ! MAINLINE BARREL RADIUS
900   Mbw=13                              !   "        "    WIDTH
910   Mlc=1600                            !   "      DRUM CAPACITY
920   Hbr=16                              ! HAULBACK BARREL RADIUS
930   Hbw=28.75                           !   "        "    WIDTH
940   Hlc=3700                            !   "        DRUM CAPACITY
950   Tower=50                            ! TOWER HEIGHT
960   Hh1=Tower
970   !**********************************************************************
980   !
990   INPUT "PRESSURE SETTING ON INTERLOCK (PSI)?",Psi
1000  M=Psi*250                           ! TORQUE AVAILABLE AT INTERLOCK
1010  Diam=7/8                            ! MAINLINE DIAMETER
1020  Diah=7/8                            ! HAULBACK DIAMETER
1030  W1=1.42                             ! WEIGHT /FOOT OF HAULBACK
1040  W3=1.42                             ! WEIGHT/FOOT OF MAINLINE
1050  Wc=600                              ! WEIGHT OF CARRIAGE
1060  Count=0
1070  J=0
1080  !********************** LOG DRAG PARAMETERS ***************************
1090  !
1100  Ll=32                               ! LOG LENGTH
1110  Hc=3                                ! CARRIAGE HEIGHT
1120  U=.6                                ! COEFFICIENT OF FRICTION
1130  Choke=24                            ! CHOKER LENGTH (FEET)
1140  Logdia=2                            ! LOG DIAMETER (FEET)
1150  Ce=Choke-PI*Logdia                  ! EFFECTIVE CHOKER LENGTH
1160  Fly=Ll+Ce+Hc                        ! REQ. CLEARANCE TO FLY
1170  !
1180  !**********************************************************************
1190  !
```

```
1200 IF Tp1=0 THEN
1210   First=2
1220 ELSE
1230   First=Tp1+1
1240 END IF
1250 FOR I=First TO Eyd
1260 !************************* FIND LOAD PATH ******************************
1270 !
1280   Drag=0
1290   G=0                        ! COUNTER FOR Dy ITERATION
1300   Sclear(I)=0
1310   Beta(I)=0
1320   IF .01*A(I)>U THEN         ! TEST FOR SLOPE GREATER THAN
1330     Slide=1                  ! COEFFICIENT OF FRICTION
1340   ELSE
1350     Slide=0
1360   END IF
1370   IF Drag>0 THEN
1380     GOSUB 4400               ! LOG DRAG SUBROUTINE
1390   ELSE
1400     GOSUB 4160               ! FULL SUSPENSION SUBROUTINE
1410   END IF
1420 !
1430 !*********************** CALCULATE LINE LENGTHS ***********************
1440 !
1450   Hrt=Dy(I)-Lh
1460   L3(I)=SQR(Dlt(I)^2+Dy(I)^2)
1470   Mrig(I)=L3(I)+Tower                                ! MAINLINE OUT
1480   Hrig(I)=L3(I)+2*SQR(Drt(I)^2+Hrt^2)+Tower          ! HAULBACK OUT
1490   Skyl(I)=Mrig(I)+Hrig(I)
1500   Ml=Mlc-Mrig(I)                                     ! MAINLINE ON DRUM
1510   Hl=Hlc-Hrig(I)                                     ! HAULBACK ON DRUM
1520   K=.2618
1530 !
1540 !*********************** CALC. WORKING HB TEN. ************************
1550 !
1560   Hn=INT((-Hbr+(Hbr^2+(Diah^2*Hl/(K*Hbw)))^.5)/Diah)+1
1570   Mn=INT((-Mbr+(Mbr^2+(Diam^2*Ml/(K*Mbw)))^.5)/Diam)+1
1580   Hre(I)=Hbr+(Hn-.5)*Diah
1590   Mre(I)=Mbr+(Mn-.5)*Diam
1600   IF G=1 THEN Hbt(I)=M/(Hre(I)/12)                   ! HAULBACK TENSION
1610   IF Drag=1 THEN Hbt(I)=M/(Hre(I)/12)                !    "       " DRAGING
1620 !
1630 !********************** COMPUTE SEGMENT FORCES ************************
1640 !
1650 !
1660 !*************************** SKYLINE LEFT ******************************
1670 !
1680   Tu=Hbt(I)                                          ! TENSION AT YARDER
1690   D=Dlt(I)
1700   Hh=Dy(I)
1710   Ww=W1
1720   GOSUB 5880
1730   V1=Vl
1740   H1=H
1750 !
1760 !
1770 !************************* SKYLINE RIGHT ******************************
1780 !
1790   IF Hrt>0 THEN
1800     Tu=Hbt(I)-W1*Lh                                  ! TU @ TAILSPAR
```

```
1810      Hh=Hrt
1820    ELSE
1830      Tu=Hbt(I)-W1*Dy(I)                              ! TU @ CARRIAGE
1840      Hh=-Hrt
1850    END IF
1860    D=Drt(I)
1870    Ww=W1
1880    GOSUB 5880
1890    H2=H
1900    IF Hrt>0 THEN V2=V1
1910    IF Hrt<0 THEN V2=-(V1+W1*L)
1920  !
1930  !*************************** HAULBACK **********************************
1940  !
1950    IF Hrt>0 THEN
1960      Tu=Hbt(I)-W1*Lh                                 !TU @ TAILSPAR
1970      Hh=Hrt
1980    ELSE
1990      Tu=Hbt(I)-W1*Dy(I)                              ! TU @ CARRAIGE
2000      Hh=-Hrt
2010    END IF
2020    D=Drt(I)
2030    Ww=W1
2040    GOSUB 5880
2050    H4=H
2060    IF Hrt>0 THEN V4=V1
2070    IF Hrt<0 THEN V4=-(V1+W1*L)
2080  !
2090  !****************** PAYLOAD AND MAINLINE TENSION **********************
2100    IF Drag>0 THEN
2110      GOSUB 3860                                      ! DRAGGING
2120    ELSE
2130      GOSUB 4010                                      !  FLYING
2140    END IF
2150  !*********************************************************************
2160    IF Drag>0 THEN
2170      IF ABS(Z)<.02*Wg THEN
2180        IF H1>=50 THEN                                ! TEST FOR SUFFICIENT
2190          GOTO 2350                                   ! HAULBACK LENGTH
2200        ELSE
2210          DISP "HAULBACK LENGTH EXCEEDED,TRY AGAIN"
2220          WAIT 4
2230          GOTO 780
2240        END IF
2250      END IF
2260    ELSE
2270      IF ABS(Z)<.02*Wg THEN 2310
2280    END IF
2290    GOTO 1370
2300    !
2310    IF C1(I)<Fly THEN                              ! TEST FOR FULL SUSPENSION
2320      Drag=1
2330      GOTO 1370
2340    END IF
2350  NEXT I
2360  !
```

```
2370  !*********************** CALC. POWER BALANCE *************************
2380  !
2390  FOR I=Tp1+2 TO Eyd STEP 2
2400    Ge(I)=1
2410    T=0
2420    Et=0
2430    IF Et>0 THEN
2440      GOSUB 3250                          ! ITERATE FOR THROTTLE SETTING
2450      GOSUB 3430                          ! CALC SPEED RATIO
2460      GOSUB 3560                          ! CALC CONVERTER TORQUE RATIO
2470      GOSUB 3660                          ! CALC ACTUAL TORQUE RATIO
2480    ELSE
2490      GOSUB 3020                          ! ITERATE FOR ENGINE SPEED
2500      GOSUB 3430                          ! CALC SPEED RATIO
2510      GOSUB 3560                          ! CALC CONVERTER TORQUE RATIO
2520      GOSUB 3660                          ! CALC ACTUAL TORQUE RATIO
2530    END IF
2540    IF Mout(I)<0 THEN  GOTO 2840          ! TEST FOR NEGATIVE OUTPUT TORQUE
2550    Zt=Tr(I)-Trc(I)
2560    IF Et=0 THEN                          ! FIRST ITERATION OF ENGINE SPEED
2570      IF T=0 THEN                         ! ROUTINE (GOV SPD), MUST REDUCE
2580        IF Zt<0 THEN                      ! THROTTLE SETTING IF Zt IS NEG.
2590          Et=1
2600          GOTO 2430
2610        END IF
2620      END IF
2630    END IF
2640    IF ABS(Zt)<.001 THEN             ! IS OPERATING COND. ERROR ACCEPTABLE?
2650      IF Ke(I)<49.86 THEN            ! IS OPERATING COND. FEASIBLE?
2660        IF Ge(I)=1 THEN
2670          PRINT "INFEASIBLE LOAD AT TP#";I/2
2680          GOTO 2840
2690        ELSE
2700          Ge(I)=Ge(I)-1              ! DOWN-SHIFT IF POSSIBLE
2710          T=0
2720          GOTO 2430
2730        END IF
2740      END IF
2750    ELSE
2760      T=T+1
2770      GOTO 2430
2780    END IF
2790    GOSUB 3730                            ! CALC POWER LOST AT INTERLOCK
2800    GOSUB 5770                            ! CALC AVE POWER LOST THROUGH
2810    !                                       CLUTCH
2820    Hpreq(I)=Me(I)*Erpm(I)/5252           ! CALC REQUIRED HORSE POWER
2830    Re(I)=(Pml(I)-Phb(I))/Hpreq(I)        ! CALC RELATIVE EFFICIENCY
2840  NEXT I
2850  !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
2860  GOSUB 5390                              ! PRINT OUTPUT
2870  INPUT "DO YOU WISH TO CHANGE YARDER LOCATION OR TAILHOLD GEOMETRY ?",T$
2880  IF T$="NO" THEN 2970
2890  INPUT "NEW YARDER LOCATION ?",Tp1
2900  INPUT "NEW LOCATION OF TAILHOLD AND HEIGHT ?",Tp2,Hh2
2910  PRINT USING 650;Tp1
2920  PRINT
2930  PRINT USING 680;Hh2,Tp2
2940  PRINT
2950  Tp1=2*Tp1
2960  Tp2=2*Tp2
2970  Brake=0
2980  Gl=0
2990  GOTO 780
3000  END       !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
```

```
3010 !
3020 !------------------- SUBROUTINE VARIES ENGINE SPEED --------------------
3030 !
3040 IF T=0 THEN Erpm(I)=2100           ! TRIAL ENGINE SPEED (GOV SPEED)
3050 IF T=1 THEN
3060   Erpm(I)=1652
3070   Delta=200
3080 END IF
3090 IF T>1 THEN
3100   IF Zt<0 THEN
3110     Erpm(I)=Erpm(I)+Delta          ! INCREASE RPM IF NEED LESS TORQUE
3120   ELSE
3130     Erpm(I)=Erpm(I)-Delta/2        ! DECREASE RPM IF NEED MORE TORQUE
3140     Delta=Delta/2
3150   END IF
3160 END IF
3170 IF Erpm(I)>=1652 THEN
3180   Me(I)=1286.64071-.11172*Erpm(I)  ! CALC. ENGINE TORQUE AS FCN. OF RPM
3190 ELSE
3200   Me(I)=1102.07944
3210 END IF
3220 Ke(I)=Erpm(I)/SQR(Me(I))           ! CALC. CAPACITY FACTOR
3230 RETURN
3240 !
3250 !----------------- SUBROUTINE VARIES THROTTLE SETTING ------------------
3260 !
3270 IF Et=1 THEN
3280   Erpm(I)=2100                      ! SET ENGINE AT GOV. SPEED
3290   Ke(I)=49.86                       ! TRIAL THROTTLE SETTING
3300   Delta=10
3310   Et=Et+1
3320 ELSE
3330   IF Zt<0 THEN
3340     Ke(I)=Ke(I)+Delta               ! INCREASE Ke IF NEED LESS TORQUE
3350   ELSE
3360     Ke(I)=Ke(I)-Delta/2             ! DECREASE Ke IF NEED MORE TORQUE
3370     Delta=Delta/2
3380   END IF
3390 END IF
3400 Me(I)=Erpm(I)^2/Ke(I)^2             ! CALC. ENGINE TORQUE AS FCN. OF
3410 RETURN                              ! THROTTLE SETTING
3420 !
3430 !------------------ SUBROUTINE CALCULATES SPEED RATIO ------------------
3440 !
3450 !
3460 IF Ke(I)<52.9 THEN Src(I)=(Ke(I)-49.86)*.050775      ! TD-11500-MS340
3470 IF Ke(I)>=52.9 THEN
3480   IF Ke(I)<=63.38 THEN
3490     Src(I)=.00010*EXP(.13956*Ke(I))
3500   ELSE
3510     Src(I)=.01534*EXP(.0606*Ke(I))-.02011
3520   END IF
3530 END IF
3540 RETURN
3550 !
3560 !------------ SUBROUTINE CALCULATES CONVERTER TORQUE RATIO -------------
3570 !
3580 IF Src(I)<=.709 THEN                            ! TD-11500-MS340
3590   Trc(I)=5.0812*EXP(-2.2878*Src(I))
3600 ELSE
3610   Trc(I)=-.11566-3.35498*LOG(Src(I))
```

```
3620 END IF
3630 Tce(I)=Trc(I)*Src(I)                          ! CALC. CONVERTER EFFICIENCY
3640 RETURN
3650 !
3660 !------------- SUBROUTINE CALCULATES ACTUAL TORQUE RATIO ---------------
3670 !
3680 Mml(I)=Mlt(I)*(Mre(I)/12)                   ! MAIN DRUM TORQUE
3690 Mout(I)=(Mml(I)-M*Rinp)*Rmain*Gear(Ge(I))/Egear ! CONV OUTPUT TORQUE
3700 Tr(I)=Mout(I)/Me(I)                         ! ACTUAL TORQUE RATIO
3710 RETURN
3720 !
3730 !***************** CALCULATE POWER LOST AT INTERLOCK *******************
3740 !
3750 Dratio(I)=Mre(I)/Hre(I)                     ! DRUM RADIUS RATIO
3760 Lsr(I)=ABS((Hrig(I+1)-Hrig(I))/(Mrig(I+1)-Mrig(I)))  !LINE SPEED RATIO
3770 Mrpm(I)=Src(I)*Erpm(I)*Rmain*Gear(Ge(I)) ! MAIN DRUM RPM
3780 Mlspd(I)=Mrpm(I)*(Mre(I)/12)*2*PI          ! MAINLINE SPEED
3790 Pml(I)=Mml(I)*Mrpm(I)/5252                  ! POWER IN MAINLINE
3800 Hbspd(I)=Mlspd(I)*Lsr(I)                    ! HAULBACK SPEED
3810 Phb(I)=Hbt(I)*Hbspd(I)/33000                ! POWER IN HAULBACK
3820 Dn(I)=Mrpm(I)*(Dratio(I)*Lsr(I)-Rinp)      ! DIFFERENTIAL SPEED
3830 Pl(I)=M*Dn(I)/5252                          ! POWER DISSIPATED AT INTERLOCK
3840 RETURN
3850 !
3860 !^^^^^^^^^^^^^^^^^^^^ COMPUTE NET PAYLOAD DRAGGING ^^^^^^^^^^^^^^^^^^^^
3870 !
3880 Wnet=((Dy(I)/Dlt(I))*(H4+H2-H1)-.5*W3*L3(I)-Wc+V1+V2+V4)/(N1-N2*Dy(I)/Dl
t(I))
3890 Wv(I)=Wnet*N1
3900 Wh=Wnet*N2
3910 !
3920 !^^^^^^^^^^^^^^^^^^ CALC DRAGGING MAINLINE TENSION ^^^^^^^^^^^^^^^^^^^
3930 !
3940 H3=H2+H4-H1+Wh
3950 V3=Wv(I)+Wc-V1-V2-V4
3960 MIt(I)=SQR(H3^2+V3^2)+W3*Dy(I)                ! MAINLINE TENSION
3970 Z=Wnet-Wq                                      ! DRAGGING PAYLOAD ERROR
3980 Sclear(I)=Cc+Hc-Xp*TAN(Theta(I))               ! DRAGGING SKYLINE CLEARANCE
3990 RETURN
4000 !
4010 !******************* CALC SUSPENDED MAINLINE TENSION *******************
4020 !
4030 H3=H2+H4-H1
4040 V3=H3*Dy(I)/Dlt(I)-.5*W3*L3(I)
4050 Mlt(I)=SQR(H3^2+(V3+W3*L3(I))^2)
4060 !
4070 !******************** COMPUTE NET PAYLOAD SUSPENDED ********************
4080 !
4090 W=V1+V2+V3+V4-Wc                            ! NET PAYLOAD
4100 IF G=0 THEN Wo=W
4110 Cl(I)=Y(Tp1)+Hh1-Dy(I)-Y(I)                 ! CALC SKYLINE CLEARANCE
4120 Flc(I)=Cl(I)-Fly                            ! CALC SUSPENDED LOG CLEARANCE
4130 Z=W-Wq                                      ! SUSPENDED PAYLOAD ERROR
4140 RETURN
4150 !
4160 !@@@@@@@@@@@@@ SUBROUTINE FOR FULLY SUSPENDED DEFLECTION @@@@@@@@@@@@@@@
4170 !
4180 Dlt(I)=X(I)-X(Tp1)                          ! SEGMENT GEOMETRY
4190 Drt(I)=X(Tp2)-X(I)
4200 Span=Drt(I)+Dlt(I)
```

```
4210 Lh=((Y(Tp1)+Hh1)-(Y(Tp2)+Hh2))
4220 IF G=0 THEN
4230   Dyi=Dlt(I)*Lh/Span                        ! 1st GUESS FOR DEFLECTION
4240   Dy(I)=Dyi
4250 END IF
4260 IF G=1 THEN
4270   Dy(I)=Dyi+Span/100                        ! 2nd GUESS FOR DEFLECTION
4280   Wo=W
4290 END IF
4300 IF G>1 THEN
4310   Slope=(W-Wo)/(Dy(I)-Dyi)
4320   Wo=W
4330   Dyi=Dy(I)
4340   Dy(I)=(Wg-Wo)/Slope+Dyi                   ! NEW GUESS FOR DEFLECTION
4350 END IF
4360 G=G+1
4370 RETURN
4380 !@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
4390 !
4400 !################# SUBROUTINE FOR DRAGGING DEFLECTION ##################
4410 !
4420 Flc(I)=0
4430 Theta(I)=-ATN(.01*A(I))                      ! GROUND ANGLE
4440 !
4450 !********************* LOG TO GROUND ANGLE (BETA) **********************
4460 !
4470 IF Slide>0 THEN 4810
4480 IF Drag=1 THEN                               ! CONDITION 1&2
4490 !
4500   Betao=ASN(Logdia/Ll)+2                     ! 1st GUESS FOR BETA
4510   Lay=Betao                                  !  (LOWER LIMIT)
4520   Beta(I)=Betao
4530 END IF
4540 IF Drag=2 THEN
4550   Beta(I)=89-Theta(I)                        ! 2nd GUESS FOR BETA
4560   Hang=Beta(I)                               !  (UPPER LIMIT)
4570   Wo=Wnet
4580 END IF
4590 IF Drag>2 THEN
4600   Slope=(Wnet-Wo)/(Beta(I)-Betao)
4610   Wo=Wnet
4620   Betao=Beta(I)
4630   Step=(Wg-Wo)/Slope
4640   Beta(I)=Step+Betao                         ! NEW GUESS FOR BETA
4650   IF Beta(I)>Hang THEN
4660     Step=Step/2
4670     GOTO 4640
4680   END IF
4690   IF Beta(I)<Lay THEN                        ! KEEP SEARCH WITHIN
4700     Step=Step/2                              ! UPPER AND LOWER BOUNDS
4710     GOTO 4640
4720   END IF
4730   IF Beta(I)<Lay+.1 THEN                     ! CHECK FOR SUFFICIENT
4740     IF Betao<Lay+.1 THEN                     ! TENSION/DEFLECTION
4750       DISP "INSUFFICIENT HAULBACK TENSION AT TP#";I/2
4760       WAIT 4
4770       GOTO 2870
4780     END IF
4790   END IF
4800 END IF
```

```
4810  IF Slide=1 THEN                                  ! CONDITION 3 (LOG SLIDES)
4820    Betao=180                                      ! 1st GUESS FOR BETA
4830    Lay=Betao                                      !   (UPPER LIMIT)
4840    Beta(I)=Betao
4850  END IF
4860  IF Slide=2 THEN
4870    Beta(I)=89-Theta(I)                            ! 2nd GUESS FOR BETA
4880    Hang=Beta(I)                                   !  (LOWER LIMIT)
4890    Wo=Wnet
4900  END IF
4910  IF Slide>2 THEN
4920    Slope=(Wnet-Wo)/(Beta(I)-Betao)
4930    Wo=Wnet
4940    Betao=Beta(I)
4950    Step=(Wg-Wo)/Slope
4960    Beta(I)=Step+Betao                             ! NEW GUESS FOR BETA
4970    IF Beta(I)<Hang THEN
4980      Step=Step/2
4990      GOTO 4960
5000    END IF
5010    IF Beta(I)>Lay THEN                            ! KEEP SEARCH WITHIN
5020      Step=Step/2                                  ! UPPER AND LOWER BOUNDS
5030      GOTO 4960
5040    END IF
5050    IF Beta(I)>179.9 THEN                          ! CHECK FOR SUFFICIENT
5060      IF Betao>179.9 THEN                          ! TENSION/DEFLECTION
5070        DISP "INSUFFICIENT HAULBACK TENSION AT TP#";I/2
5080        WAIT 4
5090        GOTO 2870
5100      END IF
5110    END IF
5120  END IF
5130  !
5140  !************************* TAGLINE ANGLE ****************************
5150  !
5160  Kk=2*(1+U*TAN(Beta(I)))
5170  N1=1-(COS(Theta(I))-SIN(Theta(I))*TAN(Beta(I)))*(COS(Theta(I))-U*SIN(The
ta(I)))/Kk
5180  N2=(COS(Theta(I))-SIN(Theta(I))*TAN(Beta(I)))*(SIN(Theta(I))+U*COS(Theta
(I)))/Kk
5190  Alpha=ATN(N2/N1)
5200  !
5210  Ga=Beta(I)+Theta(I)-ATN(Logdia/L1)
5220  Lc(I)=L1*SIN(Ga)-(L1*COS(Ga)*TAN(Theta(I)))      ! CALC LOG END CLEARANCE
5230                                                   !   (VERTICAL)
5240  !
5250  !********************** COMPUTE SEGMENT GEOMETRY **********************
5260  !
5270  Xp=L1*COS(Beta(I)+Theta(I))+Ce*SIN(Alpha)
5280  Cc=L1*SIN(Beta(I)+Theta(I))+Ce*COS(Alpha)
5290  Dlt(I)=X(I)-X(Tp1)-Xp
5300  Drt(I)=X(Tp2)-X(I)+Xp
5310  Span=Drt(I)+Dlt(I)
5320  Lh=((Y(Tp1)+Hh1)-(Y(Tp2)+Hh2))
5330  Dy(I)=Y(Tp1)+Hh1-Cc-Hc-Y(I)                      ! DEFLECTION
5340  Drag=Drag+1
5350  IF Slide>0 THEN Slide=Slide+1
5360  RETURN
5370  !####################################################################
5380  !
```

```
5390  !************************** PRINT OUTPUT ******************************
5400  !
5410  PRINT
5420  PRINT
5430  PRINT "T.P.     MLT        HBT    REQUIRED   LSPD   SUSPENSION   LOG CLE
ARANCE   BETA"
5440  PRINT "         (LBS)      (LBS)     H.P.     (FPM)                    (
FT)      (DEG)  "
5450  PRINT
5460  FOR I=Tp1+2 TO Eyd STEP 2
5470    Tp=I/2
5480    IF Mout(I)>0 THEN
5490      IF Flc(I)>0 THEN
5500        PRINT USING 5620;Tp,Mlt(I),Hbt(I),Hpreq(I),Mlspd(I),Flc(I),Beta(I)
5510      ELSE
5520        PRINT USING 5630;Tp,Mlt(I),Hbt(I),Hpreq(I),Mlspd(I),Lc(I),Beta(I)
5530      END IF
5540    ELSE
5550      IF Flc>0 THEN
5560        PRINT USING 5640;Tp,Mlt(I),Hbt(I),Flc(I),Beta(I)
5570      ELSE
5580        PRINT USING 5650;Tp,Mlt(I),Hbt(I),Flc(I),Beta(I)
5590      END IF
5600      Brake=1
5610    END IF
5620    IMAGE 3D,5X,5D,6X,5D,5X,4D,6X,4D,5X,"FULL",11X,3D,8X,3D
5630    IMAGE 3D,5X,5D,6X,5D,5X,4D,6X,4D,5X,"PART",11X,3D,8X,3D
5640    IMAGE 3D,5X,5D,6X,5D,5X,"   *   ",6X,"*     ","FULL",11X,3D,8X,3D
5650    IMAGE 3D,5X,5D,6X,5D,5X,"   *   ",6X,"*     ","PART",11X,3D,8X,3D
5660  NEXT I
5670  IF Brake=1 THEN
5680    PRINT
5690    PRINT "* NEGATIVE ENGINE TORQUE REQUIRED,SPEED INFORMATION NOT AVAILAB
LE"
5700  END IF
5710  PRINT
5720  PRINT USING 5730;Apl
5730  IMAGE "AVE. HORSE POWER DISSIPATED AT INTERLOCK CLUTCH=",3D.2D
5740  PRINT
5750  RETURN
5760  !
5770  !***************** SUBROUTINE FOR AVE. HP DISSAPATION ******************
5780  !
5790  J=J+1
5800  IF J=1 THEN
5810    Tpl=Pl(I)
5820  ELSE
5830    Tpl=Pl(I)+Tpl
5840  END IF
5850  Apl=Tpl/J
5860  RETURN
5870  !
5880  !************* SUBROUTINE FOR H,V (RIGID LINK MOMENT ARMS) *************
5890  !
5900  L=SQR(D^2+Hh^2)
5910  H=Tu*D/L*SQR(1-(.5*Ww*D/Tu)^2)-.5*Ww*D*Hh/L
5920  Vl=H*Hh/D-.5*Ww*L
5930  RETURN
```

EXAMPLE OF VARIABLE RATIO, HYDRAULIC INTERLOCK RUNNING SKYLINE MODEL

INPUT

Profile:

TERRAIN POINT	X	Y	SLOPE DIST	% SLOPE
0	0.00	1000.00	0.00	0.00
1	136.79	938.45	150.00	-45.00
2	322.48	864.17	200.00	-40.00
3	461.76	808.46	150.00	-40.00
4	647.45	734.18	200.00	-40.00
5	786.72	678.47	150.00	-40.00
6	972.42	604.19	200.00	-40.00
7	986.58	599.24	15.00	-35.00
8	1086.58	599.24	100.00	0.00
9	1228.15	648.79	150.00	35.00
10	1369.73	698.34	150.00	35.00

Yarder:

Washington Iron Works model 118

Head spar/tailspar geometry:

YARDER IS LOCATED AT T.P.# 0

TAILHOLD IS 20 FEET HIGH AT T.P.# 10

External yarding limit:

Terrain point #6

Hydraulic pressure at interlock:

######## INTERLOCK PRESSURE HELD CONSTANT AT 1850 PSI ########

Design payload:

PAYLOAD= 5000

OUTPUT

T.P.	MLT (LBS)	HBT (LBS)	REQUIRED H.P.	LSPD (FPM)	SUSPENSION	LOG CLEARANCE (FT)	BETA (DEG)
1	14210	11648	290	1576	PART	24	46
2	13614	10977	261	1620	PART	17	33
3	13375	10977	249	1639	PART	19	36
4	12402	10379	139	1453	PART	23	45
5	11503	10379	93	1601	PART	31	68
6	10582	9842	*	*	FULL	42	0

* NEGATIVE ENGINE TORQUE REQUIRED,SPEED INFORMATION NOT AVAILABLE

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Item	Line Numbers
"Dummy" terrain points	340-400
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All variables that are subscripted for retrieval from memory, are listed between lines 110 and 180. For internal calculations, the subscripts are twice the terrain point value. For example, the torque converter efficiency at terrain point #4 is designated as Tce(8).

```
10   !******************** VARIABLE RATIO HYDRAULIC *************************
20   !
30   ! USES MODIFIED SECANT SEARCH PROCEDURE TO FIND LOAD PATH
40   !
50   !
60   !
70   PRINT PAGE
80   !
90   INPUT "NAME OF PROFILE YOU WISH TO USE",F$     ! READS PROFILE DATA
100  DEG
110  DIM S(100),A(100),X(100),Y(100),Ss(100),Aa(100),Sclear(100),Beta(100)
120  DIM Dy(100),L3(100),Mrig(100),Hrig(100),Drt(100),Dlt(100),Skyl(100)
130  DIM Hre(100),Mre(100),Dratio(100),Hbt(100),Cl(100),Lsr(100),Mp(100)
140  DIM Ke(100),Erpm(100),Me(100),Mi(100),Mml(100),Mout(100),Tr(100)
150  DIM Trc(100),Src(100),Mrpm(100),Mlspd(100),Dn(100),Pm(100),Pp(100)
160  DIM Pl(100),Tce(100),Wnet(100),Wv(100),Mlt(100),Theta(100),Lc(100)
170  DIM Ge(100),Alpha(100),Hpreq(100),Flc(100),Hbspd(100),Pml(100),Phb(100)
180  DIM Spt(100),Dispp(100),Re(100)
190  ASSIGN #1 TO "WILBANKS/"&F$
200  N=0
210  Nn=0
220  READ #1;X(0),Y(0)
230  FOR I=1 TO 100                          ! LOAD EVEN # PTS. INTO ARRAY
240    J=2*I                                  ! (ACTUAL TERRAIN POINTS)
250    READ #1;Ss(I),Aa(I)
260    IF ABS(Ss(I))+ABS(Aa(I))=0 THEN 340
270    A=ATN(Aa(I)/100)
280    X(J)=X(J-2)+Ss(I)*COS(A)
290    Y(J)=Y(J-2)+Ss(I)*SIN(A)
300    S(J)=Ss(I)
310    A(J)=Aa(I)
320    N=N+1
330  NEXT I
340  FOR I=0 TO N                            ! LOAD ODD # PTS. INTO ARRAY
350    J=2*I+1                                !(DUMMY TERRAIN POINTS)
360    X(J)=X(J-1)+.01*(X(J+1)-X(J-1))
370    Y(J)=Y(J-1)+.01*(Y(J+1)-Y(J-1))
380    S(J)=.01*Ss(I+1)
390    A(J)=Aa(I+1)
400    Nn=Nn+1
410  NEXT I
420  N=N+Nn-1
430  ASSIGN #1 TO *
440  PRINT "WILBANKS/"&F$
450  PRINT
460  S(0)=0
470  A(0)=0
480  PRINT "TERRAIN POINT        X          Y         SLOPE DIST    % SLOPE"
490  !
500  J=0
510  FOR I=0 TO N STEP 2                      ! PRINTS PROFILE DATA
520    Tp=I-J
530    PRINT USING 540;Tp,X(I),Y(I),S(I),A(I)
540    IMAGE 4X,4D,9X,5D.2D,2X,5D.2D,4X,5D.2D,4X,5D.2D
550    J=J+1
560  NEXT I
570  PRINT
580  INPUT "YARDER LOCATION ?",Tp1
```

```
1200 Count=0
1210 J=0
1220 Hrigmax=1
1230 Mrigmax=1
1240 !
1250 !************************ LOG DRAG PARAMETERS **************************
1260 !
1270 L1=32                                ! LOG LENGTH
1280 Hc=3                                 ! CARRIAGE HEIGHT
1290 U=.6                                 ! COEFFICIENT OF FRICTION
1300 Choke=24                             ! CHOKER LENGTH (FEET)
1310 Logdia=2                             ! LOG DIAMETER (FEET)
1320 Ce=Choke-PI*Logdia                   ! EFFECTIVE CHOKER LENGTH
1330 Fly=L1+Ce+Hc                         ! REQ. CLEARANCE TO FLY
1340 !
1350 !*********************************************************************
1360 !
1370 IF Tp1=0 THEN
1380   First=2
1390 ELSE
1400   First=Tp1+1
1410 END IF
1420 FOR I=First TO Tp2-1
1430 !************************ FIND LOAD PATH ******************************
1440 !
1450   Drag=0
1460   G=0                      ! COUNTER FOR Dy ITERATION
1470   Sclear(I)=0
1480   Flc(I)=0
1490   Beta(I)=0
1500   IF .01*A(I)>U THEN       ! TEST FOR SLOPE GREATER THAN
1510     Slide=1                ! COEFFICIENT OF FRICTION
1520   ELSE
1530     Slide=0
1540   END IF
1550   IF Drag>0 THEN
1560     GOSUB 4690
1570   ELSE
1580     GOSUB 4450
1590   END IF
1600 !
1610 !********************** CALCULATE LINE LENGTHS ************************
1620 !
1630   Hrt=Dy(I)-Lh
1640   L3(I)=SQR(Dlt(I)^2+Dy(I)^2)
1650   Mrig(I)=L3(I)+Tower                                ! MAINLINE OUT
1660   Hrig(I)=L3(I)+2*SQR(Drt(I)^2+Hrt^2)+Tower          ! HAULBACK OUT
1670   Skyl(I)=Mrig(I)+Hrig(I)
1680   Ml=Mlc-Mrig(I)                                     ! MAINLINE ON DRUM
1690   Hl=Hlc-Hrig(I)                                     ! HAULBACK ON DRUM
1700   K=.2618
1710 !
1720 !*********************** CALC. WORKING HB TEN. ************************
1730 !
1740   Hn=INT((-2*Hbr+(4*Hbr^2-4*Diah*(-Diah*Hl/(K*Hbw)))^.5)/(2*Diah))+1
1750   Mn=INT((-2*Mbr+(4*Mbr^2-4*Diam*(-Diam*Ml/(K*Mbw)))^.5)/(2*Diam))+1
1760   Hre(I)=Hbr+(Hn-.5)*Diah
1770   Mre(I)=Mbr+(Mn-.5)*Diam
1780   IF G=1 THEN Hbt(I)=.98*Mh/Hinp/(Hre(I)/12)       ! HAULBACK TENSION
1790   IF Drag=1 THEN Hbt(I)=.98*Mh/Hinp/(Hre(I)/12)    !    "      " DRAGING
1800 !
```

```
590  INPUT "LOCATION OF TAILHOLD AND HEIGHT ?",Tp2,Hh2
600  IF Tp2>Tp THEN
610     BEEP
620     DISP "TAILHOLD MUST BE BETWEEN 0 AND";Tp;"  PRESS CONT WHEN READY"
630     PAUSE
640     GOTO 590
650  END IF
660  PRINT USING 670;Tp1
670  IMAGE "YARDER IS LOCATED AT T.P.#",3D
680  PRINT
690  PRINT USING 700;Hh2,Tp2
700  IMAGE "TAILHOLD IS",3D,X,"FEET HIGH AT T.P.#",3D
710  PRINT
720  Tp1=2*Tp1
730  Tp2=2*Tp2
740  INPUT "EXTERNAL YARDING LIMIT ?",Eyd
750  Eyd=Eyd*2
760  IF Eyd=Tp2 THEN
770    Eyd=Eyd-2
780  END IF
790  !
800  !****************** RUNNING SKYLINE ANALYSIS  ***********************
810  !
820  INPUT "WEIGHT OF TURN TO BE YARDED (LBS)?",Wg
830  !
840  !******************** YARDER SPECS. FOR WIW 118 ***********************
850  !
860  Rmain=.0544                       ! SPEED RATIO : TRANS.TO ML DRUM
870  Hinp=.2857                        ! SPEED RATIO : HB DRUM/INT. SHAFT
880  Minp=.2268                        ! SPEED RATIO : MAIN DRUM/INT. SHAFT
890  Rinp=Hinp/Minp                    ! SPEED RATIO : HB TO ML
900  Gear(1)=1/5.31
910  Gear(2)=1/2.71
920  Gear(3)=1/1.4
930  Gear(4)=1/.71
940  Egear=.80                          ! OVERALL EFFICIENCY
950  Mbr=18                             ! MAINLINE BARREL RADIUS
960  Mbw=36                             !    "        "    WIDTH
970  Mlc=1620                           !    "     DRUM CAPACITY
980  Hbr=13                             ! HAULBACK BARREL RADIUS
990  Hbw=36                             !    "        "    WIDTH
1000 Hlc=3300                           !    "     DRUM CAPACITY
1010 Tower=53
1020 Hh1=Tower
1030 !*********************************************************************
1040 !
1050 INPUT "HYDRAULIC PRESSURE TO INTERLOCK (PSI)?",Psi
1060 PRINT "######## INTERLOCK PRESSURE HELD CONSTANT AT";Psi;"PSI ########"
1070 PRINT
1080 Cpump=500                          ! CHARGE PUMP PRESSURE
1090 Dpsi=Psi-Cpump                     ! HYDRAULIC PRESSURE DIFFERENTIAL
1100 Mh=Dpsi*3                          ! TORQUE AVAILABLE AT INTERLOCK
1110 !
1120 !*********************************************************************
1130 Dispm=226                          ! MOTOR DISPLACEMENT (FIXED)
1140 E=.8                               ! EFFICIENCY OF HYDROSTATIC DRIVE
1150 Diam=7/8                           ! DIA. MAINLINE
1160 Diah=7/8                           ! DIA. HAULBACK
1170 W1=1.42                            ! WEIGHT/FOOT OF HAULBACK
1180 W3=1.42                            ! WEIGHT/FOOT OF MAINLINE
1190 Wc=600                             ! WEIGHT OF CARRIAGE
```

```
1810 !*********************** COMPUTE SEGMENT FORCES ************************
1820 !
1830 !
1840 !**************************** SKYLINE LEFT *****************************
1850 !
1860   Tu=Hbt(I)                                         ! TENSION AT YARDER
1870   D=Dlt(I)
1880   Hh=Dy(I)
1890   Ww=W1
1900   GOSUB 6040
1910   V1=Vl
1920   H1=H
1930 !
1940 !
1950 !**************************** SKYLINE RIGHT ****************************
1960 !
1970   IF Hrt>0 THEN
1980     Tu=Hbt(I)-W1*Lh                                 ! TU @ TAILSPAR
1990     Hh=Hrt
2000   ELSE
2010     Tu=Hbt(I)-W1*Dy(I)                              ! TU @ CARRIAGE
2020     Hh=-Hrt
2030   END IF
2040   D=Drt(I)
2050   Ww=W1
2060   GOSUB 6040
2070   H2=H
2080   IF Hrt>0 THEN V2=Vl
2090   IF Hrt<0 THEN V2=-(Vl+W1*L)
2100 !
2110 !****************************** HAULBACK *******************************
2120 !
2130   IF Hrt>0 THEN
2140     Tu=Hbt(I)-W1*Lh                                 !TU @ TAILSPAR
2150     Hh=Hrt
2160   ELSE
2170     Tu=Hbt(I)-W1*Dy(I)                              ! TU @ CARRIAGE
2180     Hh=-Hrt
2190   END IF
2200   D=Drt(I)
2210   Ww=W1
2220   GOSUB 6040
2230   H4=H
2240   IF Hrt>0 THEN V4=Vl
2250   IF Hrt<0 THEN V4=-(Vl+W1*L)
2260 !
2270 !@@@@@@@@@@@@@@@@@@@@@@ PAYLOAD AND MAINLINE TENSION @@@@@@@@@@@@@@@@@@@@
2280   IF Drag>0 THEN
2290     GOSUB 4160                                      ! DRAGING
2300   ELSE
2310     GOSUB 4310                                      ! FLYING
2320   END IF
2330 !@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
2340 !
2350   IF Drag>0 THEN
2360     IF ABS(Z)<.02*Wq THEN
2370       IF Hl>=50 THEN                                ! TEST FOR SUFFICIENT
2380         GOTO 2540                                   ! HAULBACK LENGTH
2390       ELSE
2400         DISP "HAULBACK LENGTH EXCEEDED, TRY AGAIN."
```

```
2410          WAIT 4
2420          GOTO 3090
2430        END IF
2440      END IF
2450    ELSE
2460      IF ABS(Z)<.02*Wg THEN 2500
2470    END IF
2480    GOTO 1550
2490    !
2500    IF CI(I)<Fly THEN                         ! TEST FOR FULL SUSPENSION
2510      Drag=1
2520      GOTO 1550
2530    END IF
2540  NEXT I
2550  !************************* CALC. POWER BALANCE *************************
2560  !
2570  FOR I=Tp1+2 TO Eyd STEP 2
2580    Ge(I)=4
2590    T=0
2600    Et=0
2610    Dratio(I)=Mre(I)/Hre(I)                !DRUM RADIUS RATIO
2620    Lsr(I)=ABS((Hrig(I+1)-Hrig(I))/(Mrig(I+1)-Mrig(I)))  !LINE SPEED RATIO
2630    IF Et>0 THEN
2640      GOSUB 3230                          ! ITTERATE FOR THROTTLE SETTING
2650      GOSUB 3980                          ! CALC SPEED RATIO
2660      GOSUB 3760                          ! CALC PUMP TORQUE DEMAND
2670      GOSUB 4060                          ! TABULAR TORQUE RATIO
2680      GOSUB 3620                          ! CALC ENGINE INPUT TORQUE
2690      IF Mout(I)<0 THEN  GOTO 3050        ! TEST FOR NEGATIVE OUTPUT TORQUE
2700    ELSE
2710      GOSUB 3390                          ! ITTERATE FOR ENGINE SPEED
2720      GOSUB 3620                          ! CALC KE
2730      IF Mout(I)<0 THEN  GOTO 3050        ! TEST FOR NEGATIVE OUTPUT TORQUE
2740      GOSUB 3980                          ! CALC SPEED RATIO
2750      GOSUB 4060                          ! TABULAR TORQUE RATIO
2760      GOSUB 3760                          ! CALC PUMP TORQUE DEMAND
2770    END IF
2780    Zt=Tr(I)-Trc(I)                       ! CALC DIFF. BETWEEN Tr & Trc
2790    IF Et=0 THEN
2800      IF T=0 THEN                         ! FIRST ITERATION OF ENGINE SPEED
2810        IF Zt<0 THEN                      ! ROUTINE (GOV SPD), MUST REDUCE
2820          Et=1                            ! THROTTLE SETTING IF Zt IS NEG.
2830          GOTO 2630
2840        END IF
2850      END IF
2860    END IF
2870    IF ABS(Zt)<.001 THEN          ! IS OPERATING COND. ERROR ACCEPTABLE?
2880      IF Ke(I)<64 THEN            ! IS OPERATING COND. FEASIBLE?
2890        IF Ge(I)=1 THEN
2900          PRINT "INFEASIBLE LOAD AT TP#";I/2
2910          GOTO 3050
2920        ELSE
2930          Ge(I)=Ge(I)-1           ! DOWN-SHIFT IF POSSIBLE
2940          T=0
2950          GOTO 2610
2960        END IF
2970      END IF
2980    ELSE
2990      T=T+1
3000      Mp(I)=Mpo=0
```

```
3010      GOTO 2610
3020    END IF
3030    Hpreq(I)=Me(I)*Erpm(I)/5252          ! CALC. REQUIRED HORSE POWER
3040    Re(I)=(Pml(I)-Phb(I))/Hpreq(I)       ! CALC. RELATIVE EFFICIENCY
3050  NEXT I
3060  !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
3070  GOSUB 5680                             ! PRINT OUTPUT
3080  PRINT
3090  INPUT "DO YOU WISH TO CHANGE YARDER LOCATION OR TAILHOLD GEOMETRY?",T$
3100  IF T$="NO" THEN 3200
3110  INPUT "NEW YARDER LOCATION ?",Tp1
3120  INPUT "NEW LOCATION OF TAILHOLD AND HEIGHT ?",Tp2,Hh2
3130  PRINT USING 670;Tp1
3140  PRINT
3150  PRINT USING 700;Hh2,Tp2
3160  PRINT
3170  Tp1=2*Tp1
3180  Tp2=2*Tp2
3190  Brake=0
3200  GOTO 820
3210  END     !++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
3220  !
3230  !---------------- SUBROUTINE VARIES THROTTLE SETTING -------------------
3240  !
3250  IF Et=1 THEN
3260    Erpm(I)=2100                        ! SET ENGINE AT GOV. SPEED
3270    Ke(I)=45                            ! TRIAL THROTTLE SETTING
3280    Delta=10
3290    Et=Et+1
3300  ELSE
3310    IF Zt<0 THEN
3320      Ke(I)=Ke(I)+Delta                 ! INCREASE Ke IF NEED LESS TORQUE
3330    ELSE
3340      Ke(I)=Ke(I)-Delta/2               ! DECREASE Ke IF NEED MORE TORQUE
3350      Delta=Delta/2
3360    END IF
3370  END IF
3380  RETURN
3390  !------------------ SUBROUTINE VARIES ENGINE SPEED ---------------------
3400  !
3410  IF T=0 THEN
3420    Erpm(I)=2100                        ! TRIAL ENGINE SPEED (GOV. SPEED)
3430  END IF
3440  IF T=1 THEN
3450    Erpm(I)=1400
3460    Delta=212.5
3470  END IF
3480  IF T>1 THEN
3490    IF Zt<0 THEN
3500      Erpm(I)=Erpm(I)+Delta            ! INCREASE RPM IF NEED LESS TORQUE
3510    ELSE
3520      Erpm(I)=Erpm(I)-Delta/2          ! DECREASE RPM IF NEED MORE TORQUE
3530      Delta=Delta/2
3540    END IF
3550  END IF
3560  IF Erpm(I)<=2100 THEN
3570    Me(I)=1413.3554-.19351*Erpm(I)     ! CALC. ENG. TORQUE AS FCN. OF RPM
3580  ELSE
3590    Me(I)=11681.45707-5.08873*Erpm(I)
3600  END IF
3610  RETURN
```

```
3620  !---------- SUBROUTINE CALCULATES CONVERTER CAPACITY FACTOR ------------
3630  !                      OR ENGINE TORQUE
3640  !
3650  IF Et>0 THEN Me(I)=Erpm(I)^2/Ke(I)^2+Mp(I)  !IF VARYING THROTTLE CALC Me
3660  Mi(I)=Me(I)-Mp(I)
3670  Mml(I)=Mlt(I)*(Mre(I)/12)                    ! MAIN DRUM TORQUE
3680  !
3690  Mout(I)=(Mml(I)-(.98*Mh/Minp))*Rmain*Gear(Ge(I))/Egear      !CONV OUTPUT
3700  !                                                              TORQUE
3710  !
3720  Tr(I)=Mout(I)/Mi(I)                           !ACTUAL TORQUE RATIO
3730  !
3740  IF Et=0 THEN Ke(I)=Erpm(I)/SQR(ABS(Mi(I)))   ! IF VARYING RPM CALC Ke
3750  RETURN
3760  !----------- SUBROUTINE CALCULATES PUMP TORQUE DEMAND -----------------
3770  !
3780  Mrpm(I)=Erpm(I)*Src(I)*Rmain*Gear(Ge(I))     !MAIN DRUM RPM
3790  Mlspd(I)=Mrpm(I)*(Mre(I)/12)*2*PI            !MAINLINE SPEED (FPM)
3800  Hbspd(I)=Mlspd(I)*Lsr(I)                     !HAULBACK LINE SPEED (FPM)
3810  Phb(I)=Hbspd(I)*Hbt(I)/33000                 !HAULBACK LINE POWER (HP)
3820  Pml(I)=Mlspd(I)*Mlt(I)/33000                 !MAINLINE POWER (HP)
3830  Dn(I)=Mrpm(I)*(Rinp-Dratio(I)*Lsr(I))        !DIFFERENTIAL SPEED (RPM)
3840  Pm(I)=Dn(I)*Mh/5252                          !POWER AT INTERLOCK (HP)
3850  Flow=Dispm*Dn(I)                              !HYDRAULIC FLOW (CU.IN./MIN)
3860  Dispp(I)=Flow/Erpm(I)                         !NECESSARY PUMP DISPLACEMENT
3870  Mpo=Mp(I)
3880  IF Dn(I)>0 THEN                          ! IF POWER FLOW POSITIVE
3890    Mp(I)=(Dpsi*Dispp(I)/(24*PI))/E             !PUMP TORQUE
3900    Pl(I)=Pp(I)*(1-E)                           !POWER LOST AT INTERLOCK
3910    !
3920  ELSE                                     ! IF POWER FLOW NEGATIVE
3930    Mp(I)=(Dpsi*Dispp(I)/(24*PI))*E             !PUMP TORQUE
3940    Pl(I)=-Pm(I)*(1-E)                          !POWER LOST AT INTERLOCK
3950  END IF
3960  Pp(I)=Mp(I)*Erpm(I)/5252                      ! PUMP POWER (HP)
3970  RETURN
3980  !----------------- SUBROUTINE CALCULATES SPEED RATIO -------------------
3990  !
4000  IF Ke(I)>139 THEN
4010    Src(I)=(Ke(I)-139)*.000136826+.98
4020  ELSE
4030    Src(I)=-7.364243008+.246378172*Ke(I)-.002381983*Ke(I)^2+.000007492*Ke(
I)^3-.00072861
4040  END IF
4050  RETURN
4060  !----------------- SUBROUTINE CALCULATES TORQUE RATIO ------------------
4070  !
4080  IF Src(I)>.98 THEN
4090    Trc(I)=-(Src(I)-.98)*20.71428571+.725
4100  ELSE
4110    Trc(I)=1.79-.72662374*Src(I)+.78656742*Src(I)^2-1.1345955*Src(I)^3-.04
0455877
4120  END IF
4130  Tce(I)=Src(I)*Trc(I)                          ! CALC. CONVERTER EFFICIENCY
4140  RETURN
4150  !
4160  !^^^^^^^^^^^^^^^^^^^ COMPUTE NET PAYLOAD DRAGGING ^^^^^^^^^^^^^^^^^^^^
4170  !
4180  Wnet(I)=((Dy(I)/Dlt(I))*(H4+H2-H1)-.5*W3*L3(I)-Wc+V1+V2+V4)/(N1-N2*Dy(I)
/Dlt(I))
4190  Wv(I)=Wnet(I)*N1
4200  Wh=Wnet(I)*N2
4210  !
```

```
4220 !^^^^^^^^^^^^^^^^^^ CALC DRAGGING MAINLINE TENSION ^^^^^^^^^^^^^^^^^^^^^
4230 !
4240 H3=H2+H4-H1+Wh
4250 V3=Wv(I)+Wc-V1-V2-V4
4260 Mlt(I)=SQR(H3^2+V3^2)+W3*Dy(I)
4270 Z=Wnet(I)-Wg                               !DRAGGING PAYLOAD ERROR
4280 Sclear(I)=Cc+Hc-Xp*TAN(Theta(I))           !DRAGGING SKYLINE CLEARANCE
4290 RETURN
4300 !
4310 !****************** CALC SUSPENDED MAINLINE TENSION ********************
4320 !
4330 H3=H2+H4-H1
4340 V3=H3*Dy(I)/Dlt(I)-.5*W3*L3(I)
4350 Mlt(I)=SQR(H3^2+(V3+W3*L3(I))^2)               ! MAINLINE TENSION
4360 !
4370 !******************* COMPUTE NET PAYLOAD SUSPENDED *********************
4380 !
4390 W=V1+V2+V3+V4-Wc                                ! NET PAYLOAD
4400 IF G=0 THEN Wo=W
4410 Cl(I)=Y(Tp1)+Hh1-Dy(I)-Y(I)               ! SUSPENDED SKYLINE CLEARANCE
4420 Flc(I)=Cl(I)-Fly                          ! SUSPENDED LOG CLEARANCE
4430 Z=W-Wg                                    ! SUSPENDED PAYLOAD ERROR
4440 RETURN
4450 !@@@@@@@@@@@@@@@ SUBROUTINE FOR FULLY SUSPENDED DEFLECTION @@@@@@@@@@@@@@
4460 !
4470 Dlt(I)=X(I)-X(Tp1)                        ! SEGMENT GEOMETRY
4480 Drt(I)=X(Tp2)-X(I)
4490 Span=Drt(I)+Dlt(I)
4500 Lh=((Y(Tp1)+Hh1)-(Y(Tp2)+Hh2))
4510 IF G=0 THEN
4520   Dyi=Dlt(I)*Lh/Span                     ! 1st GUESS FOR DEFLECTION
4530   Dy(I)=Dyi
4540 END IF
4550 IF G=1 THEN
4560   Dy(I)=Dyi+Span/100                     ! 2nd GUESS FOR DEFLECTION
4570   Wo=W
4580 END IF
4590 IF G>1 THEN
4600   Slope=(W-Wo)/(Dy(I)-Dyi)
4610   Wo=W
4620   Dyi=Dy(I)
4630   Dy(I)=(Wg-Wo)/Slope+Dyi                ! NEW GUESS FOR DEFLECTION
4640 END IF
4650 G=G+1
4660 RETURN
4670 !@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
4680 !
4690 !################# SUBROUTINE FOR DRAGGING DEFLECTION ##################
4700 !
4710 Flc(I)=0
4720 Theta(I)=-ATN(.01*A(I))                    ! GROUNG ANGLE
4730 !
4740 !******************** LOG TO GROUND ANGLE (BETA) ***********************
4750 !
4760 IF Slide>0 THEN 5100
4770 IF Drag=1 THEN                            ! CONDITION 1&2
4780 !
4790   Betao=ASN(Logdia/L1)+5                  ! 1st GUESS FOR BETA
4800   Lay=Betao                               !  (LOWER LIMIT)
4810   Beta(I)=Betao
```

```
4820  END IF
4830  IF Drag=2 THEN
4840    Beta(I)=90-Theta(I)                    ! 2nd GUESS FOR BETA
4850    Hang=Beta(I)                           !  ( UPPER LIMIT)
4860    Wo=Wnet(I)
4870  END IF
4880  IF Drag>2 THEN
4890    Slope=(Wnet(I)-Wo)/(Beta(I)-Betao)
4900    Betao=Beta(I)
4910    Wo=Wnet(I)
4920    Step=(Wg-Wo)/Slope
4930    Beta(I)=Step+Betao                     ! NEW GUESS FOR BETA
4940    IF Beta(I)>Hang THEN
4950      Step=Step/2
4960      GOTO 4930
4970    END IF                                 ! KEEP SEARCH WITHIN UPPER
4980    IF Beta(I)<Lay THEN                    ! AND LOWER BOUNDS
4990      Step=Step/2
5000      GOTO 4930
5010    END IF
5020    IF Beta(I)<Lay+.1 THEN                 ! CHECK FOR SUFFICIENT
5030      IF Betao<Lay+.1 THEN                 ! TENSION/DEFLECTION
5040        DISP "INSUFFICIENT DEFLECTION AT TP#";I/2
5050        WAIT 4
5060        GOTO 3080
5070      END IF
5080    END IF
5090  END IF
5100    IF Slide=1 THEN                        ! CONDITION 3 (LOG SLIDES)
5110      Betao=180                            ! 1st GUESS FOR BETA
5120      Lay=Betao                            !   (UPPER LIMIT)
5130      Beta(I)=Betao
5140    END IF
5150    IF Slide=2 THEN
5160      Beta(I)=89-Theta(I)                  ! 2nd GUESS FOR BETA
5170      Hang=Beta(I)                         !   (LOWER LIMIT)
5180      Wo=Wnet(I)
5190    END IF
5200    IF Slide>2 THEN
5210      Slope=(Wnet(I)-Wo)/(Beta(I)-Betao)
5220      Betao=Beta(I)
5230      Wo=Wnet(I)
5240      Step=(Wg-Wo)/Slope
5250      Beta(I)=Step+Betao                   ! NEW GUESS FOR BETA
5260      IF Beta(I)<Hang THEN
5270        Step=Step/2
5280        GOTO 5250
5290      END IF
5300      IF Beta(I)>Lay THEN                  ! KEEP SEARCH WITHIN
5310        Step=Step/2                        ! UPPER AND LOWER BOUNDS
5320        GOTO 5250
5330      END IF
5340      IF Beta(I)>179.9 THEN                ! CHECK FOR SUFFICIENT
5350        IF Betao>179.9 THEN                ! TENSION/DEFLECTION
5360          DISP "INSUFFICIENT HAULBACK TENSION AT TP#";I/2
5370          WAIT 4
5380          GOTO 820
5390        END IF
5400      END IF
5410    END IF
5420  !
```

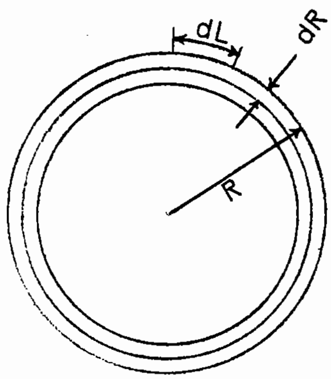
```
 5430  !*************************** TAGLINE ANGLE *****************************
 5440  !
 5450    Kk=2*(1+U*TAN(Beta(I)))
 5460    N1=1-(COS(Theta(I))-SIN(Theta(I))*TAN(Beta(I)))*(COS(Theta(I))-U*SIN(T
heta(I)))/Kk
 5470    N2=(COS(Theta(I))-SIN(Theta(I))*TAN(Beta(I)))*(SIN(Theta(I))+U*COS(The
ta(I)))/Kk
 5480    Alpha(I)=ATN(N2/N1)
 5490  !
 5500    Ga=Beta(I)+Theta(I)-ATN(Logdia/L1)
 5510    Lc(I)=L1*SIN(Ga)-(L1*COS(Ga)*TAN(Theta(I)))  ! CALC LOG END CLEARANCE
 5520                                                 !     (VERTICAL)
 5530  !
 5540  !********************* COMPUTE SEGMENT GEOMETRY **********************
 5550  !
 5560    Xp=L1*COS(Beta(I)+Theta(I))+Ce*SIN(Alpha(I))
 5570    Cc=L1*SIN(Beta(I)+Theta(I))+Ce*COS(Alpha(I))
 5580    Dlt(I)=X(I)-X(Tp1)-Xp
 5590    Drt(I)=X(Tp2)-X(I)+Xp
 5600    Span=Drt(I)+Dlt(I)
 5610    Lh=((Y(Tp1)+Hh1)-(Y(Tp2)+Hh2))
 5620    Dy(I)=Y(Tp1)+Hh1-Cc-Hc-Y(I)                  ! DEFLECTION
 5630    Drag=Drag+1
 5640    IF Slide>0 THEN Slide=Slide+1
 5650    RETURN
 5660  !######################################################################
 5670  !
 5680  !*************************** PRINT OUTPUT *****************************
 5690  !
 5700    PRINT
 5710    PRINT
 5720    PRINT "T.P.     MLT       HBT     REQUIRED   LSPD   SUSPENSION   LOG C
LEARANCE  BETA"
 5730    PRINT "        (LBS)     (LBS)      H.P.    (FPM)                     (
FT)      (DEG)  "
 5740    PRINT " "
 5750    FOR I=Tp1+2 TO Eyd STEP 2
 5760      Tp=I/2
 5770      IF Mout(I)>0 THEN
 5780        IF Me(I)>0 THEN
 5790          IF Flc(I)>0 THEN
 5800            PRINT USING 5930;Tp,Mlt(I),Hbt(I),Hpreq(I),Mlspd(I),Flc(I),Bet
a(I)
 5810          ELSE
 5820            PRINT USING 5940;Tp,Mlt(I),Hbt(I),Hpreq(I),Mlspd(I),Lc(I),Beta
(I)
 5830          END IF
 5840        END IF
 5850      ELSE
 5860      IF Flc(I)>0 THEN
 5870        PRINT USING 5950;Tp,Mlt(I),Hbt(I),Flc(I),Beta(I)
 5880      ELSE
 5890        PRINT USING 5960;Tp,Mlt(I),Hbt(I),Lc(I),Beta(I)
 5900      END IF
 5910        Brake=1
 5920      END IF
 5930      IMAGE 3D,5X,5D,6X,5D,5X,4D,6X,4D,5X,"FULL",11X,3D,8X,3D
 5940      IMAGE 3D,5X,5D,6X,5D,5X,4D,6X,4D,5X,"PART",11X,3D,8X,3D
 5950      IMAGE 3D,5X,5D,6X,5D,5X,"   *    ",6X,"*     ","FULL",11X,3D,8X,3D
 5960      IMAGE 3D,5X,5D,6X,5D,5X,"   *    ",6X,"*     ","PART",11X,3D,8X,3D
```

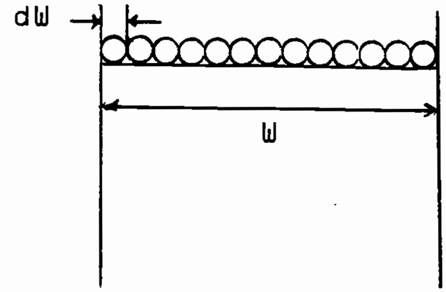
```
5970    NEXT I
5980    IF Brake=1 THEN
5990      PRINT
6000      PRINT "* NEGATIVE ENGINE TORQUE REQUIRED,SPEED INFORMATION NOT AVAIL
ABLE"
6010    END IF
6020    RETURN
6030    !
6040    !************* SUBROUTINE FOR H,V (RIGID LINK MOMENT ARMS) *************
6050    !
6060    L=SQR(D^2+Hh^2)
6070    H=Tu*D/L*SQR(1-(.5*Ww*D/Tu)^2)-.5*Ww*D*Hh/L
6080    V1=H*Hh/D-.5*Ww*L
6090    RETURN
```

APPENDIX III

DERIVATIONS

NUMBER OF WRAPS

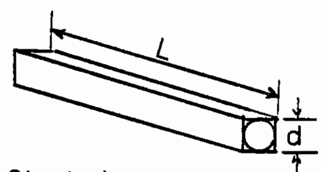




Sketch a

Sketch b

From Sketch a:



Sketch c

$$d\ \text{Volume} = dL\ dR\ dW$$

$$\text{Volume} = \int dL \int dR \int dW$$

$$\int dL = R\int d\theta = 2\pi R$$

$$\int dW = W$$

$$\text{Volume} = 2\pi\ W \int R\ dR$$

Length of the wire rope equals the volume divded by the cross-sectional area of the rope. If it is assumed that the rope is "stacked" on the drum as illustrated in Figure 10, and the effects of crushing are neglected, the cross-sectional area is equivalent to the square of the rope diameter (sketch c).

Therefore:

$$L = \frac{2\pi W \int R\, dR}{d^2}$$

This gives L in inches. A more convenient unit is feet. L in feet equals:

$$L = \frac{2\pi W \int R\, dR}{12d^2} = \frac{2\pi W}{12d^2} \int_{b_r}^{br + nd} R\, dR = W\pi \left[\frac{(b_r+nd)^2}{2} - \frac{b_r^2}{2}\right]$$

$$L = \frac{.2618\ W \left[(b_r+nd^2)-b_r^2\right]}{d^2}$$

Letting K = .2618 and solving for n yields

$$n = \frac{-b_r + \left[(b_r^2 + \frac{d^2L}{KW})\right]^{.5}}{d}$$

HYDRAULIC PUMP TORQUE

$$M_p = (\ p)(Dp)$$

Displacement (D_p) is measured in cubic inches per revolution

$$Mp = (lb/in^2)(in^3) = lb\text{-}in/rev.$$

To convert to pound-feet:

$$M_p = (lb\text{-}in/rev.)(1\ ft/12\ in)(1\ rev./2\pi\ radians) = lb\text{-}ft$$