AN ABSTRACT OF THE THESIS OF

Chris B. Ledoux for the degree of Master of Science in Forest Engineering presented on 2/28/75

Title: SIMULATION OF A HELICOPTER YARDING SYSTEM IN OLD GROWTH FOREST STANDS

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Dean Edward Aulerich

Helicopter yarding systems have become a popular tool in removing timber from steep slopes, sensitive soils, limited access areas, and environmentally sensitive stands. Little is known about the system's dynamics. This study is part of a research project to explore "advanced" logging systems as to their economic efficiency and environmental applications.

The objectives of my study were:

1 To identify and isolate variables that significantly influence helicopter yarding efficiency.

2 To develop a simulation model that will simulate the response of the helicopter yarding operations to changes in these variables.

I observed a medium lift (Boeing-Vertol 107 Model II) helicopter operation yarding from old growth stands under varying conditions. The helicopter yarding cycle was broken down into four cycle elements and four delay elements. I used the method of continuous timing to observe these elements and obtain values for the variables that influence these elements.

Multiple linear regression analysis was used to analyze the effect of these variables on time required to complete each cycle element. Regression equations were developed for two cycle elements; outhaul and inhaul. Other cycle elements and delay elements were analyzed employing frequency distributions. A paired t-test was used to establish the reliability of the regression equations to predict element times.

A FORTRAN simulation model was used to simulate the yarding system. The model can be used to estimate efficiency, production rates, and delay times for a wide range of yarding situations.

I experimented with the finished model and, based on those results, made suggestions for system improvements.

# Simulation Of A Helicopter Yarding System In Old Growth Forest Stands

by

Chris B. Ledoux

A THESIS

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Date thesis is presented 2/28/75

Typed by Shirley Monroe for Chris B. Ledoux

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LIST OF TABLES

# Simulation Of A Helicopter Yarding System In Old Growth Forest Stands

## I. INTRODUCTION

The helicopter is one of the most versatile forms of timber transport. With its unlimited maneuvering ability and its independence of roads, it has access to all forested lands; including the most rugged slopes and terrain. The helicopter's independence of roads and terrain types, fused with its ability to transport timber aerially has made helicopter logging an important new forestry tool available to the resource manager.

The removal of logs from timbered areas by means of helicopters was considered as early as the late 1950's and early 1960's (Forest Industries, 1971). Walbridge (1960) considered the possibility of timber transport by means of helicopter in the Tennessee Valley area only to conclude that helicopters were economically out of the question at that time. Two years later, O'Leary (1962), in cooperation with the Forest Service, investigated the feasibility of helicopter logging in the Pacific Northwest and Alaska. O'Leary found that helicopter manufacturers were expressing interest in this new approach to logging. Other countries were not sitting idle; in 1964, Samset in Norway was also studying the feasibility of logging with a Bell 204-B. Samset (1964) concluded that the operation would have to be well organized to fully justify the use of such an expensive machine.

It was not until the Plumas National Forest (Region V) advertised a sale in their Lights Creek area to be logged by skyline that helicopter logging came into commercial existence. After careful evaluation, it became evident that it would be more feasible to log the sale by helicopter because of the extremely steep terrain and highly erosive soils. The sale was logged employing a Sikorsky S61-A helicopter owned by Columbia-Construction Helicopters of Portland, Oregon, in agreement with Erickson Lumber Company of Marysville, California (Ellis, 1971). This operation is believed to have pioneered commercial helicopter logging. Since that time, much interest has been generated in favor of using this "infinitely mobile" yarder to remove severed timber from the stump to the landing.

The Forest Service has taken a strong interest in this new tool. The following figures illustrate the fact that helicopter logging is playing a role in timber management. Region VI offered 100 million board feet on it's National Forests to be yarded by helicopter in 1971. Casey (1972) claims, in his discussions with Forest Service personnel, that the Pacific Northwest Region included some 200 million additional board feet to be offered for helicopter sales in 1972 and 1973.

Helicopter logging has progressed at such a rapid rate that little is known of the efficiency, environmental impact, and economical application of helicopter logging.

Timber harvesting operations have been challenged by increasing demands for wood products (Ellis, 1971) along with increasing demands from environmental interests (American Pulpwood Association, 1972). This has forced the logging industry to seek alternatives to conventional systems (Binkley, 1971) and attempt to improve on existing logging systems.

In reply to the abovementioned challenge, the Pacific Northwest Forest and Range Experiment Station, USDA Forest Service, and Oregon State University's Department of Forest Engineering have initiated a cooperative research project to explore "advanced" logging systems (e.g., balloons, suspended skylines, and helicopters) (Dykstra, 1973). This project has so far provided an understanding of some of the factors that influence yarding efficiency along with a comparative analysis of production rates and costs.

Other than the above study, little has been done in attempting to quantify variables and their relationships as they affect helicopter yarding systems. The research described in this paper was conducted for the purpose of quantifying variables and their relationships as they affect helicopter yarding efficiency.

## II. OBJECTIVES

My study takes a portion of Dykstra's data (the helicopter portion) and further analyzes it, employing regression techniques and simulation principles to:

1) Identify and isolate variables that significantly influence helicopter yarding efficiency.
2) Develop a simulation model that will simulate the response of the helicopter yarding operation to changes in these variables.

To achieve these objectives, I used the method of continuous timing to observe a helicopter clear-cut yarding operation. I evaluated the yarding system with multiple regression analysis and constructed a computer model in FORTRAN to simulate the helicopter yarding system.

# III. PROCEDURES

## Area and Unit Layout

Data was gathered during the period of July 30, 1973, through August 16, 1973. The total period of observation was eleven days (see Table 1 for a detailed listing of individual daily statistics).

A Boeing-Vertol 107 Model II helicopter was observed during the above period. A total of 934 observations (complete turns) were recorded. The vehicle was the property of Columbia-Construction Helicopters based in Portland, Oregon. The operation took place on the Camelsback Timber sale set aside by the Mt. Hood National Forest. The sale was located in Township 6 South, Range 5 East, Section 14, Willamette Meridian. A map of the unit and the observed flight paths can be found in Appendix A.

## Yarding System and Description

The Boeing-Vertol is classified as a medium-lift helicopter with the following characteristics:[1]

| | |
|---|---|
| Engines . . . . . | General Electric CT58-110-2 gas turbine (2) |
| Take off power (TOP). . . . . | 1,250 shaft hp (each engine) |
| Maximum continuous power (MCP) . . . . . | 1,050 shaft hp (each engine) |
| Rated rotorspeed . . . . . | 265 rpm |
| Maximum forward airspeed at MCP . . . . . | 148 knots (170 mph) at sea level |
| Average cruise speed . . . . | 134 knots (154 mph) at sea level |
| Fuel consumption . . . . . | 180 gal/hr (JP-4 aircraft turbine fuel) |

[1]Boeing, 1967.

Table 1. Comparison of Observed Daily Statistics

| Date of Observation | Total Turns | Outhaul* (min.) | Hook (min.) | Inhaul* (min.) | Unhook (min.) | Tagline Length (feet) | Sydist (feet) | Chord Slope (%) | Nlogs | Bfvol/Nlog (fbm/log) |
|---|---|---|---|---|---|---|---|---|---|---|
| July 30, 1973 | 27 | 1.48 | .78 | 1.35 | .029 | 150 | 4567 | 8.3 | 1.74 | 396.55 |
| July 31, 1973 | 59 | 1.33 | .61 | 1.17 | .010 | 150 | 4641 | 7.3 | 2.20 | 313.20 |
| August 1, 1973 | 97 | 1.33 | .63 | 1.13 | .026 | 200 | 4209 | 7.6 | 1.56 | 440.33 |
| August 2, 1973 | 99 | 1.42 | .56 | 1.23 | .019 | 200 | 4218 | 5.1 | 1.71 | 401.86 |
| August 3, 1973 | 51 | 1.36 | .57 | 1.15 | .031 | 200 | 4439 | 4.9 | 2.27 | 403.43 |
| August 7, 1973 | 25 | .52 | .45 | .34 | .060 | 150 | 507 | 47.9 | 2.00 | 346.00 |
| August 8, 1973 | 75 | 1.50 | .79 | 1.27 | .008 | 150 | 433 | 13.9 | 2.50 | 275.33 |
| August 9, 1973 | 93 | 1.35 | .62 | 1.18 | .025 | 150 | 4189 | 15.8 | 2.38 | 289.06 |
| August 14, 1973 | 117 | .93 | .58 | .82 | .035 | 175 | 1890 | 50.3 | 1.64 | 451.95 |
| August 15, 1973 | 125 | .71 | .65 | .70 | .027 | 150 | 1740 | 48.7 | 1.72 | 400.46 |
| August 16, 1973 | 166 | .80 | .58 | .80 | .037 | 150 | 1470 | 11.0 | 1.79 | 384.95 |
| Averages | 85 | 1.11 | .62 | .97 | .029 | 166 | 3061 | 21.0 | 1.90 | 449.70 |

*Both outhaul and inhaul times include acceleration and deceleration.

| | |
|---|---|
| Forward rate of climb at (MCP) . . . . . | 1,700 ft/min at sea level |
| Vertical rate of climb at (TOP) . . . . . | 1,240 ft/min at sea level |
| Fuselage length . . . . . | 44' 7" |
| Fuselage width . . . . . | 7' 3" |
| Length overall (includes rotors). . . . . | 83' 4 " |
| Height . . . . . | 16' 10" |
| Rotor diameter . . . . . | 50' 0" |
| Wheel base . . . . . | 24' 11" |

This model helicopter has a net load lift capacity calculated as follows:[2]

| | |
|---|---|
| Maximum gross lifting capacity[3]. . . . . | 22,000 lbs. |
| Less: | |
| Weight of vehicle (empty) . . . . . | 9,530 lbs. |
| 30 minutes' (Average) fuel supply (90 gal @ 6.2 lbs/gal) . . . . . | 550 lbs. |
| Pilot and co-pilot @ 200 lbs . . . . . | 400 lbs. |
| Tagline, Hook Assembly and chokers . . . . . | 250 lbs. |
| Net External Load . . . . . | 11,270 lbs. |

Typical helicopter yarding activities include a helicopter lifting off from the landing, then flying to a hook-up point. The hooker inserts the choker eyes into the electrically controlled hook (Figure 1). The hooker retreats to a safe position and gives the pilot the signal to lift the load. The load is lifted clear of the ground and flown to the landing and the logs are released by the pilot with an electrical mechanism.

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[2]Casey (1972).

[3]At sea level, with atmospheric temperature of 59° F., barometric pressure of 29.92 inches of mercury.

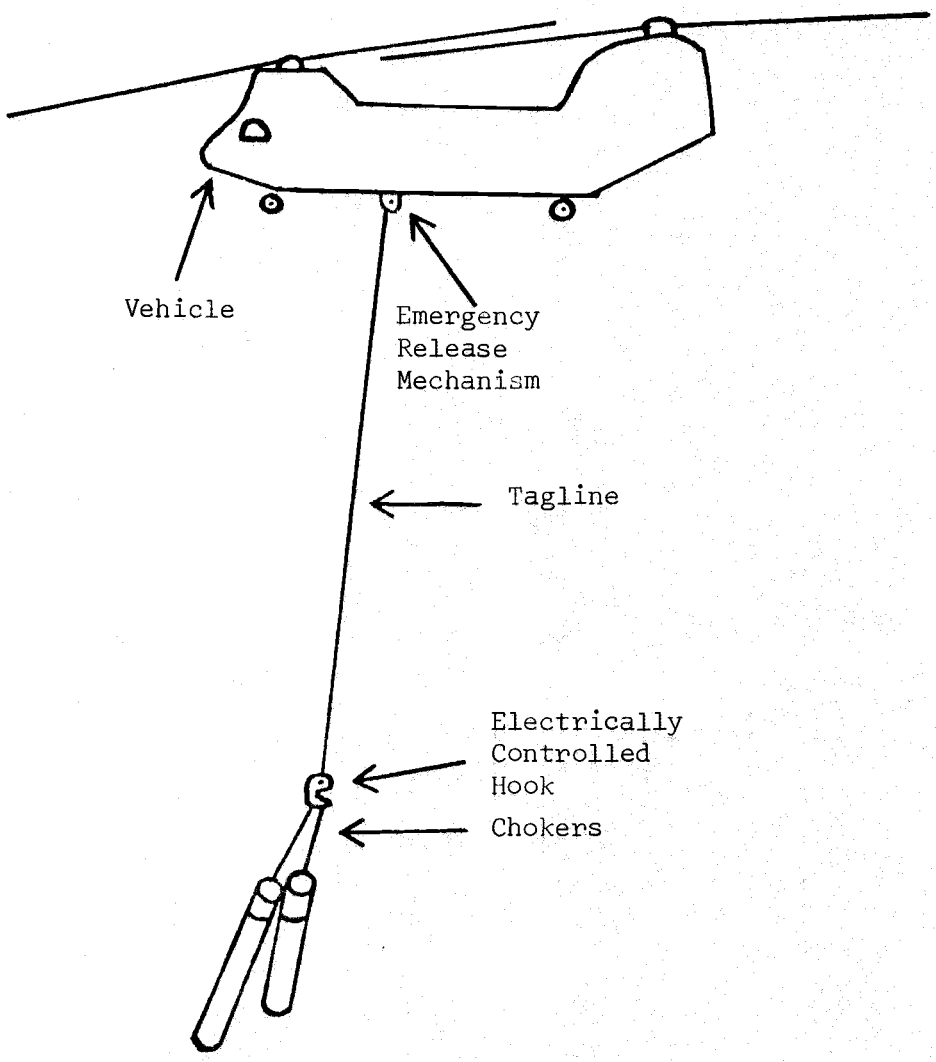



Figure 1. Yarding Configuration

*Diagram courtesy of Dennis Dykstra (1974).

## Crew Size and Location

A two-man crew gathered the data. To facilitate the data collection, one man was positioned at the landing and the other man was positioned near the hooker. This enabled the two men to fully observe and record all phases of the yarding system.

## Timing Method

The method of continuous timing was used in which the stop watches are started at the beginning of the timing period and run continuously until the timing period ends (this usually involved the entire day). The cumulative time corresponding to the event occurrence was recorded upon beginning of that event. Individual times for each element were later calculated by subtraction. Times were recorded to the nearest 1/10 minute.

## Elements of The Yarding Cycle

The cycle elements are defined as follows:

OUTHAUL - Time required to move the helicopter from the landing to the hook-up point. Outhaul time was recorded as beginning when the logs from the previous turn were released from the hook at the landing and ending when the hooker first had contact with the hook or when the hook was in position for the hooker to grasp. Outhaul time would include any maneuvering of the vehicle involved in delivering the hook to the hooker.

HOOK - Time required for the hooker to insert the eyes of the chokers into the hook mechanism. Hook time would also include any time required for the hooker to move to a safe position before the turn was lifted. Hook time was recorded as beginning when the hooker had contact with the hook for the first time or when the hook was in position to be grasped, and ending when the logs left the ground for the inhaul.

INHAUL- Time required to transport the load of logs from the hook-up point to the landing. Inhaul time was recorded as beginning when the logs left the ground for the first time and ending when the logs touched the ground for the first time at the landing.

UNHOOK- Time required to unhook the logs at the landing. Unhook time was recorded as beginning when the first log touched the ground and ending when the choker eyes were released from the hook.

Although the elements vertical-in and vertical-out did not exist in this study, they would become two more elements to consider when yarding from a partial cut and could be defined as follows:

VERTICAL-IN - Time required to lower the hook through the existing canopy to the hooker.

VERTICAL-OUT- Time required to lift the load of log(s) from the hook-up point through the existing canopy before proceeding toward the landing.

## DELAYS

The above series of elements assumes normal yarding; that is--that no delays occur to interrupt or terminate the cycle. Figure 2 shows a brief description of each factor or delay that may occur during or prior to the respective cycle element.

For example, the hook might hang up as the load is lifted out during the vertical-out element, resulting in a time loss. Or, as the loaded helicopter proceeds toward the landing, the pilot may have to wait for the loader operator to remove logs from the releasing point.

The following delays were the only delays with sufficient observations for meaningful analysis.

ABORT - An abort delay occurred whenever the hooker's choice (log(s) hooked) for that turn was beyond the lifting capacity of the ship. The pilot would then wait until the hooker was in a safe position before aborting (releasing the turn) and proceeding to hook another turn. Abort durations observed ranged from .1 minutes to 4.0 minutes.

CHOKER HOOK UP - A choker hook up delay occurred whenever the ship interrupted its flight momentarily to hover over the chasers [3a] while they hooked bundled chokers for return to the rigging crew. As chokers arrived and accumulated at the landing, they were wrapped and bundled (20 to 30 per bundle) for return to the choker setters.

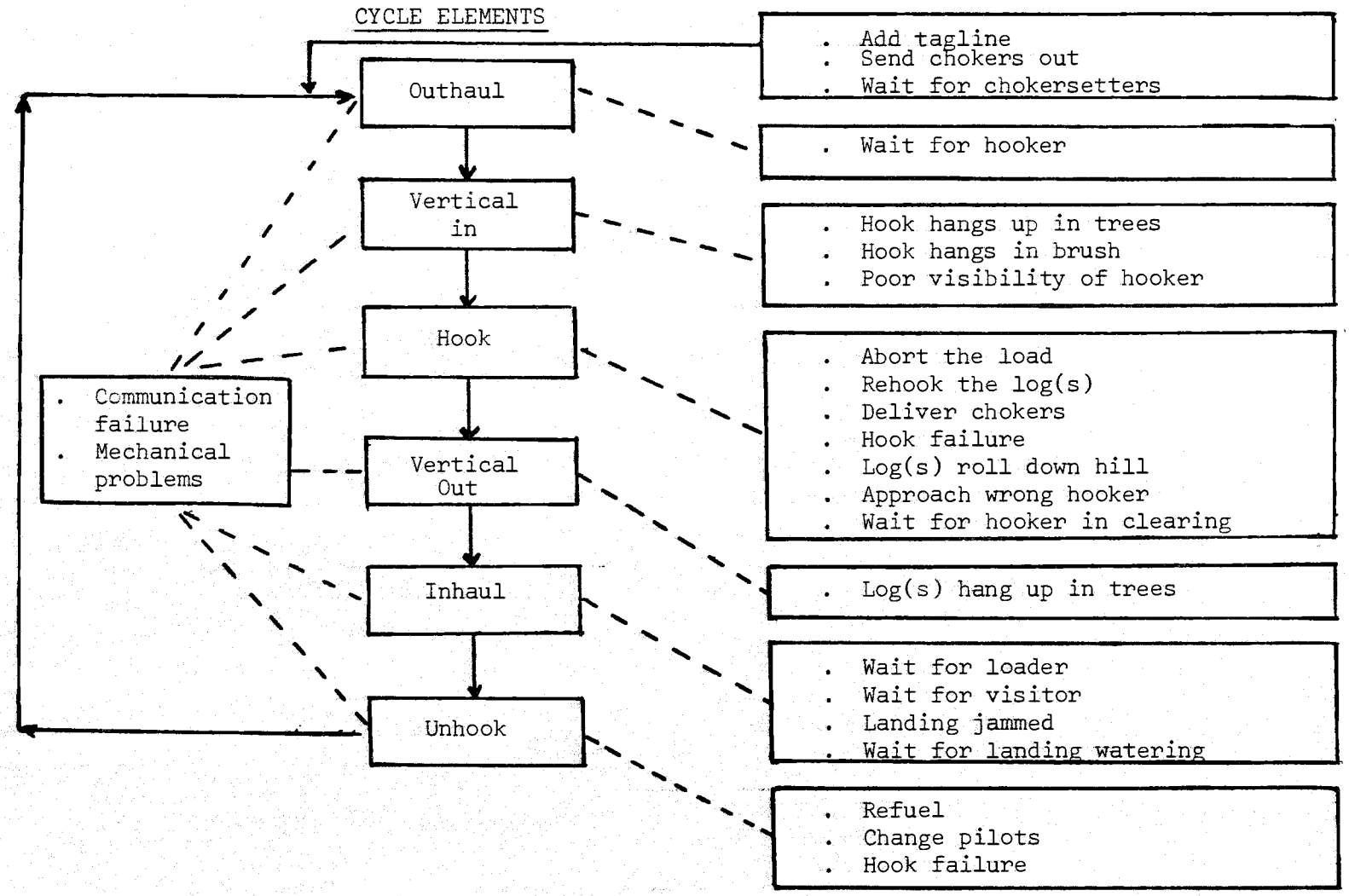



Figure 2. Delays affecting cycle elements

Choker hook up delay durations observed ranged from .1 minutes to 1.2 minutes.

CHOKER
DELIVERY - Each occurrence of a choker hook up event would automatically trigger a choker delivery delay. After hooking the bundled chokers, the ship would enter the outhaul event. Upon arrival at the hook-up point, the pilot would proceed to deliver the bundled chokers to the rigging crew (which at times was situated a good distance from the hooker). The chokers were delivered and a member of the rigging crew would hook a turn or the ship would return to the hooker for a turn. Choker delivery durations observed ranged from .1 minutes to 2.0 minutes.

REHOOK - A rehook delay occurred whenever the turn (two logs or more) was beyond the lifting capacity of the ship.
However, I chose at the time of data collection to define a rehook delay as occurring only if the turn (two logs or more) could not be lifted by the ship. At this point, the pilot would not abort the load; he would simply lower the turn allowing the hooker to release one or more logs. Rehook durations observed ranged from .4 minutes to 3.0 minutes.

REFUELING- This delay involved the aircraft landing and taking on enough fuel for the next cycle. Refueling event occurrence observed ranged from 13 turns to 43 turns.

The two delays listed on the left side of the flowchart (Figure 2) could occur at any element execution and would usually result

in a termination of the cycle until the problem was located and taken care of. The majority of the listed factors and delays would result in a time loss of a similar sort.

## Field Measurements

To understand the efficiency of this system, I chose element time or the time required to complete each event as the dependent variable. The independent variables measured are listed below.

Board Foot Volume (BFVOL) - Gross board foot volume per turn, including any unmerchantable material. The small end diameter and length of each log were supplied by Columbia Construction landing crews and the values were later approximated by Knouf's Rule[4].

Board Foot Volume per Log (BFVOL/NLOGS) - Gross board foot volume per log.

Chordslope (CHORDSLP) - Slope (%) of a line segment connecting the landing and the hook-up point. CHORDSLP is equal to the difference in elevation between the two points divided by the horizontal distance between the two points multiplied by one hundred to convert to percent. This value was recorded as a positive value when yarding downhill and a negative value when yarding uphill.

[4]As explained in Dilworth, J.R., Log Scaling and Timber Cruising, Rev. ed. Corvallis, Oregon State University Bookstore, 1962, p. 18.

Slope Yarding Distance (SYDIST) - Yarding distance recorded along the slope, in feet. The hook-up point was recorded for each turn on a contour map (contour interval of 80 feet). The horizontal distance to the landing was measured from the map and slope distance was calculated using the difference in elevation between the two points.

Tagline Length (TAGLINE) - Length of tagline in feet.

Number of Logs (NLOGS) - Number of logs yarded for each turn.

The crewman at the designated point recorded the items listed in Table 2.

Table 2. Position of Recorded Variables

| Cycle Time | Where Recorded | |
|---|---|---|
| | Landing | Rigging |
| Outhaul start time | X | |
| Outhaul end time | | X |
| Hook start time | | X |
| Hook end time | | X |
| Inhaul start time | | X |
| Inhaul end time | X | |
| Unhook start time | X | |
| Unhook end time | X | |
| Abort time | | X |
| Rehook time | | X |
| Choker hook-up time | X | |
| Choker delivery time | | X |
| Refuel time | X | |
| Pieces per turn | X | |
| Volume measurements | X | |
| Length of tagline | X | |

# IV. DATA ANALYSIS

## Regression Analysis

The yarding system was analyzed with regression techniques and simulation principles. Use of these two techniques in combination enabled a more complete look at the interaction of significant variables.

Since the opportunity of selecting a second sample did not exist, I chose to randomly dichotomize the original 934 observations in order to create two samples from the same population. Sample I contained 456 observations, while Sample II contained 478 observations. The respective equations listed below were constructed utilizing the observations in Sample II. Sample I was used to test the equations.

<u>Outhaul</u> = .52873 $R^2$ = .545

- .00059546 (TAGLINE)* $S^2$ = .077

+ .00022581 (SYDIST) *****

Each variable that was expected to influence outhaul time was introduced into the equations, first alone and then in the presence of other variables. Slope yarding distance (SYDIST) and the

---

Levels of significance

* = .20

*** = .05

***** = .01

length of the tagline (TAGLINE) explained 54 percent of the variation in outhaul times. Slope yarding distance (SYDIST) increased outhaul times as the ship traveled further from the landing. This variable behaves as one would expect and confirms findings by Wood (1962). The effect of a longer tagline is to decrease outhaul time. One possible explanation may be that a shorter tagline would result in a considerable propeller down-wash (compacted air traveling at high speeds pushed down by the rotor blades) making it difficult to place the hook in a position to be grasped by the hooker. This compacted air traveling at high speeds would also restrict the hooker in movement. Further study may be directed at this problem.

<u>Hook</u> = .57396 $R^2$ = .015

+ .041716 (NLOGS)*** $S^2$ = .132

- .000070954 (BFVOL)*

Hook time underwent similar treatment in entering alone, and in combination, factors that could possibly influence hook time. Number of logs (NLOGS) and Board foot volume (BFVOL) combined proved to be significant. The above combination, although significant in nature, explained only little over one percent of the variation in hook times. Since the coefficient of determination was only .015, I, therefore, chose not to use a regression equation for hook time. The amount of variation observed in hooking times was not significant as shown in Table 1. Samset (1964) also found that very little variation in hooking time existed in his study. An explanation might be that since the hooker is properly selecting the pre-marked turn

to be hooked (or giving some thought as to what is to be hooked), the variation in hooking times may be reduced.

| | | | | | | |
|---|---|---|---|---|---|---|
| Inhaul | = | .74904 | | | | |
| | + | .00015991 | (SYDIST)***** | $R^2$ | = | .617 |
| | - | .0037517 | (CHORDSLP)***** | $S^2$ | = | .041 |
| | + | .019075 | (NLOGS)*** | | | |
| | - | .0014931 | (TAGLINE)***** | | | |
| | + | .000072418 | (BFVOL/NLOGS)*** | | | |

A look at the respective coefficients indicates that inhaul time is dependent upon Slope yarding distance (SYDIST), Chordslope (CHORDSLP), Number of logs (NLOGS), Tagline length (TAGLINE), and Board foot volume (BFVOL/NLOGS). Sixty-one percent of the variation in inhaul time was explained by the above combination of factors. The further the vehicle traveled from the landing, the longer it took to transport the load to the landing as would be expected.

Increase in Chordslope (CHORDSLP) seemed to reduce inhaul time. The relationship of Chordslope (CHORDSLP) to inhaul time should be viewed cautiously. A very steep Chordslope (CHORDSLP) would serve to increase inhaul time (Dykstra, 1974). Therefore, the behavior of Chordslope (CHORDSLP) should be analyzed further. Increasing tagline length aided in reducing inhaul time. The effect of the length of tagline (TAGLINE) may possibly be explained by the fact that upon approaching the landing, the pilot would have to lower the ship considerably further with a short

tagline as compared to a longer tagline. A longer tagline would also mean that since he did not have to lower the ship the additional distance, the vehicle would not have to again rise that distance to enter the flight path before returning for another turn. The effect of Number of logs (NLOGS) and the Board foot volume per log (BFVOL/NLOGS) was less pronounced than the variables Slope yarding distance (SYDIST), Tagline length (TAGLINE), Chordslope (CHORDSLP); as shown by their respective coefficients. Increasing both Number of logs (NLOGS) and Board foot volume per log (BFVOL/NLOGS) increased inhaul times, as would be expected. Since Number of logs (NLOGS) and Board foot volume per log (BFVOL/NLOGS) contributed such a small amount to the inhaul time, I chose to omit them in further analysis.

At this point, it would be meaningful to again review Table 1. Notice that on any given day, the vehicle took less time to transport the load as compared to the time required to move the empty vehicle to the hook-up point. This may seem the exact opposite of what one would expect, since the ship is traveling the same distance both ways. But a further look at the definitions of the cycle elements will clarify this point. Inhaul time requires little, if any, positioning of the ship, while outhaul time includes not only the time required to travel that distance, but also the time required in delivering the hook to the hooker. See Appendix B.

Unhook time was subject to such small variation (Table 1), that no attempt was made to construct a model to predict unhook times. Any variation in unhook times could be explained by the

fact that when a greater than one log turn came into the landing, the pilot would, at times, lower the logs until all log ends touched the ground surface before activating the release mechanism located in the pilot's cabin. Again a look at Table 1 will show that unhook time for all practical purposes was zero.

To further dramatize the effects of the significant variables, I chose to hold Number of Logs (NLOGS) and Board foot Volume per Log (BFVOL/NLOGS) constant varying Chordslope (CHORDSLP) and Tagline Length (TAGLINE) to produce Figure 3. This illustrates the fact that the longer the tagline, the more efficient the yarding process. Increasing Chordslope (CHORDSLP) also serves to decrease yarding times. The effect of Slope yarding distance (SYDIST) is well pronounced in each treatment. For a brief comparison, look at the differences between using a 100-foot tagline and a 300-foot tagline at a given Chordslope (CHORDSLOPE) and a given Slope yarding distance (SYDIST) of 4500 feet. A 100-foot tagline takes 3.6 minutes, while a 300-foot tagline, at the same distance, takes 3.1 minutes. This is a measurable time difference.

## Test of the Equations

Treating the 934 observations as two random samples from the same population, one half of the observations were used to construct the outhaul and inhaul equations. The remaining half of the data served to test, HO: $\hat{Y} = Y$ (hypothesis that the chosen model describes the data) against the alternate hypothesis HA:

$\hat{Y} \neq Y$ (that the chosen model is inadequate).

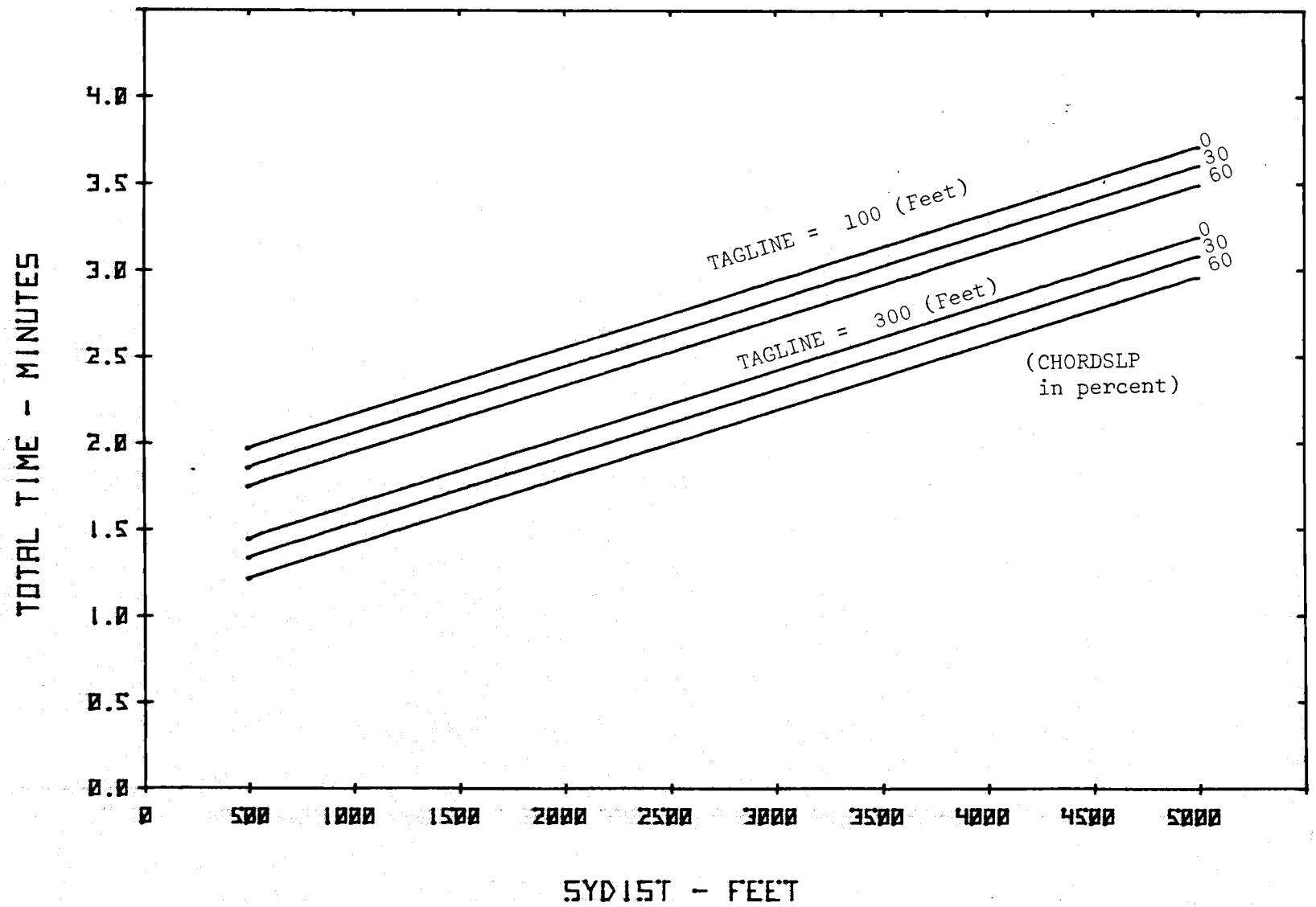



Figure 3. Comparison of SYDIST by CHORDSLP, TAGLINE = 100 Feet vs. SYDIST by CHORDSLP, TAGLINE = 300 Feet

Selecting one turn at a time from the remaining data and substituting the observed significant independent variables into the constructed models, a value was generated ($\hat{Y}$ - predicted value). Using ($\hat{Y}$) the predicted value and (Y) the observed value, we can employ the Student's t-test (Peterson, 1973) to detect whether or not the mean difference is significant. Table 3 lists the chosen equations along with pertinent statistics. The hypothesis, HO: $\hat{Y} = Y$ (the model describes the data) was accepted in both cases at the .01 level.

Table 3

| | | | |
|---|---|---|---|
| Outhaul | = .52873 | | |
| | - .00059546 (TAGLINE)* | $R^2$ | = .545 |
| | + .00022581 (SYDIST)***** | $S^2$ | = .077 |

Paired t-test

| | |
|---|---|
| sample size | 456 |
| observed mean | 1.0866 |
| predicted mean | 1.0912 |
| mean difference | -.0046 |
| standard error of the difference | .01236 |
| t- statistic | -.03782 |
| t- table value at (.99) | 2.5758 |
| accept HO: $\hat{Y} = Y$ | |

| | | | | |
|---|---|---|---|---|
| Inhaul | = .74904 | | | |
| | + .00015991 | (SYDIST)***** | $R^2$ | = .617 |
| | - .0037517 | (CHORDSLP)***** | $S^2$ | = .041 |
| | + .019075 | (NLOGS)*** | | |
| | - .0014931 | (TAGLINE)***** | | |
| | + .000072418 | (BFVOL/NLOGS)*** | | |

Paired t-test

| | |
|---|---|
| sample size | 322 |
| observed mean | .91335 |
| predicted mean | .91416 |
| mean difference | -.000812 |
| standard error of the difference | .011995 |

| | |
|---|---|
| t- statistic | -.06765 |
| t- table value at (.99) | 2.5758 |

accept HO: $\hat{Y} = Y$

## Frequency Distributions

Outhaul and inhaul were the only element functions for which I was able to construct an equation successfully. The remaining element functions and observed delays were either not statistically significant or did not occur often enough to allow correlation between factors forcing occurrences and frequency of occurrence. With this in mind, I chose to use the frequency distributions of those elements and delays in further analyses. The respective frequency distributions are found on pages 29 through page 32.

The method of recording the data resulted in discrete distributions. Since the distributions in a discrete form serve only to represent the conditions observed, I chose to construct continuous empirical distributions as follows (Gordon, 1969):

$$A_i = \frac{X_{i+1} - Xi}{Y_{i+1} \quad Yi}$$

Where, $X_i$ = x axis, time

$Y_i$ = y axis, frequency

$A_i$ = slope of X with respect to Y.

A mixed congruential random number generator was employed to generate a random variate to be used along with the above calculated slope in the following function:

$$X_j = X_i + A_i (R_j - Y_i)$$

Where, $X_j$ = desired time computed

$A_i$ = slope of X with respect to Y

$R_j$ = random number

$Y_i$ = cumulative frequency value for that desired event

For example, selecting the respective random number and selecting the discrete frequency distribution, we convert the distribution of volumes per 4 log turns (100 BF) from a discrete distribution to a continuous distribution as illustrated in Figure 22. This conversion took place in the FORTRAN program for the respective distribution.

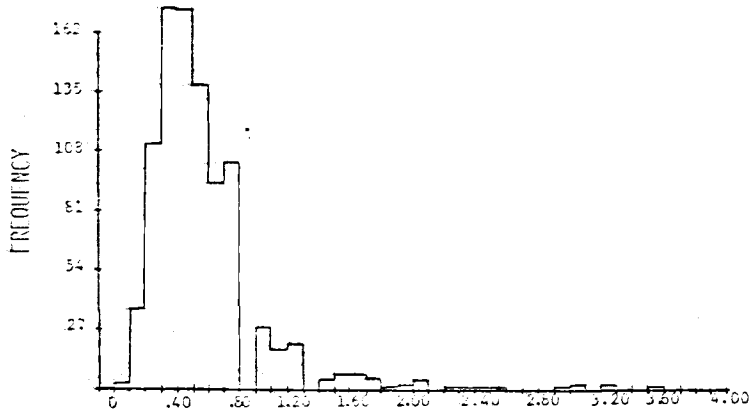



Figure 4. DISTRIBUTION OF HOOK TIME, MINUTES

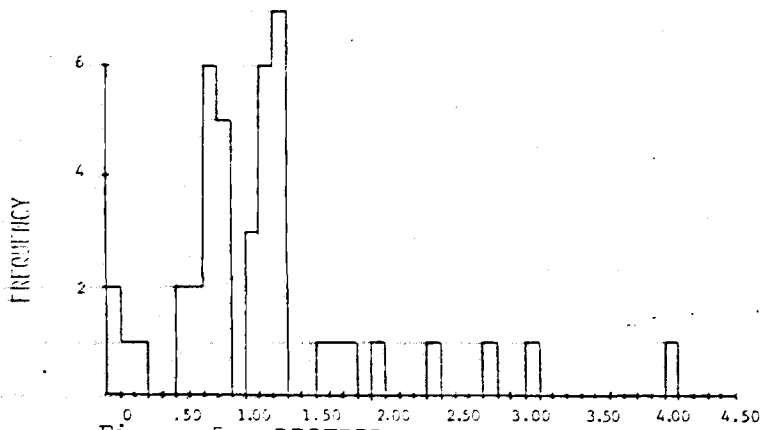



Figure 5. DISTRIBUTION OF ABORT TIME, MINUTES

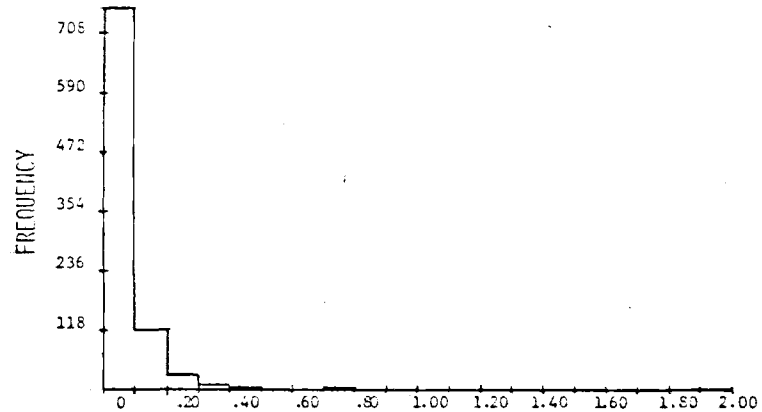



Figure 6. DISTRIBUTION OF UNHOOK TIME, MINUTES

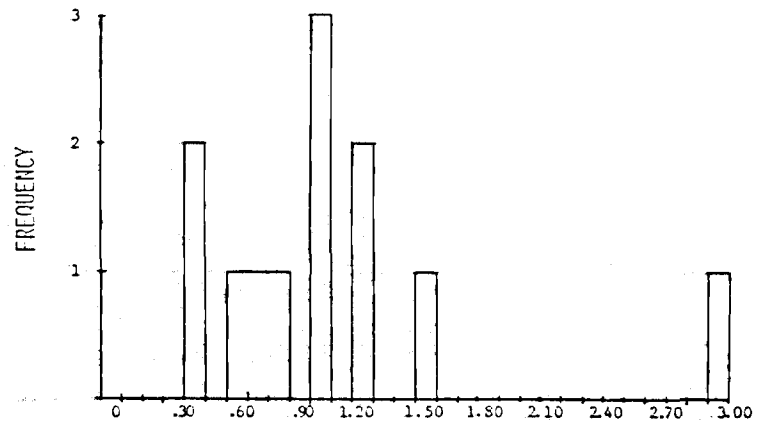



Figure 7. DISTRIBUTION OF REHOOK TIMES, MINUTES

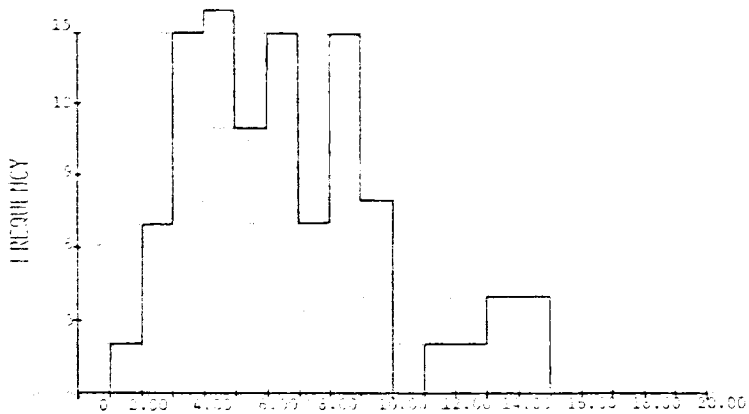



Figure 8. DISTRIBUTION OF VOLUMES PER 3 LOG TURNS, 100 BF

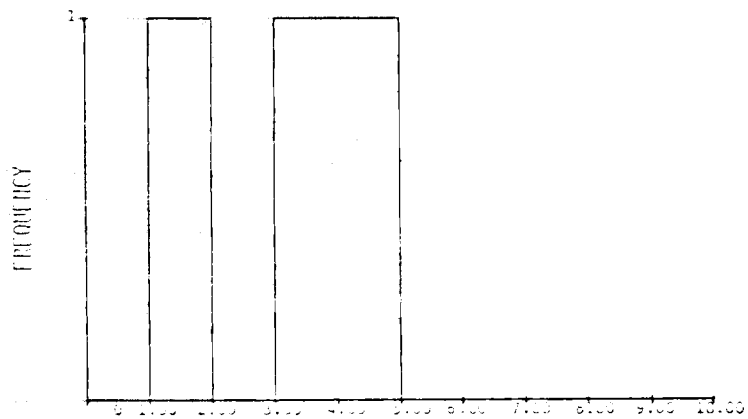



Figure 9. DISTRIBUTION OF VOLUMES PER 5 LOG TURNS, 100 BF

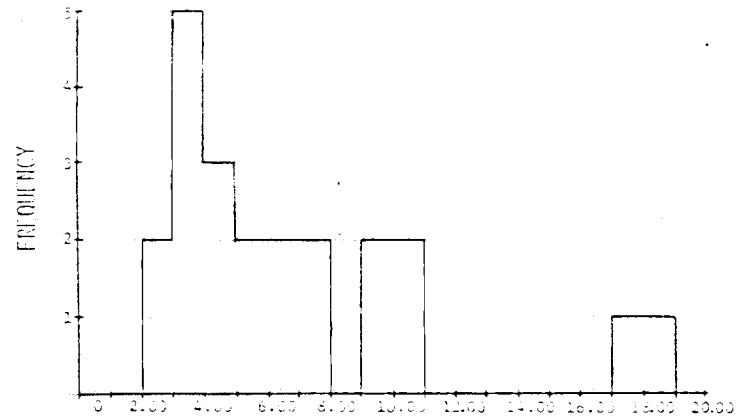



Figure 10. DISTRIBUTION OF VOLUMES PER 4 LOG TURNS, 100 BF

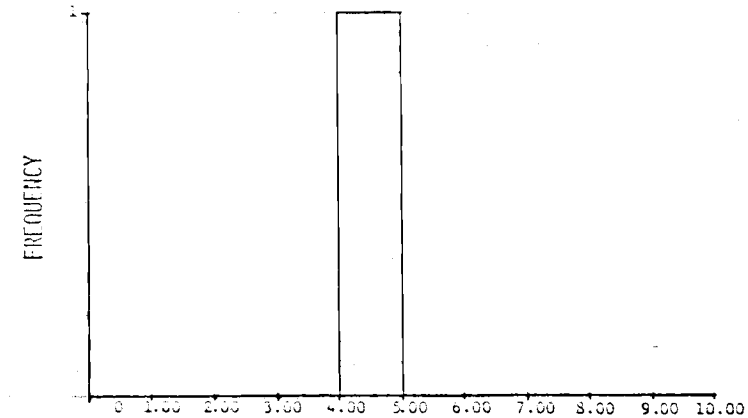



Figure 11. DISTRIBUTION OF VOLUMES PER 6 LOG TURNS, 100 BF

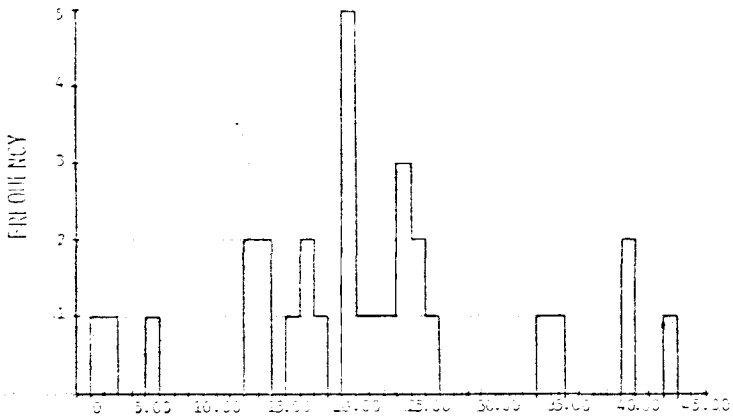



Figure 12. DISTRIBUTION OF TURNS BETWEEN REFUEL TIMES, MINUTES

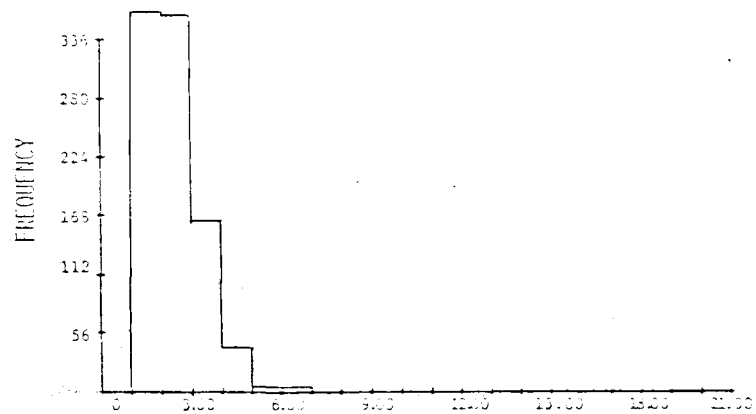



Figure 14. DISTRIBUTION OF LOGS PER TURN

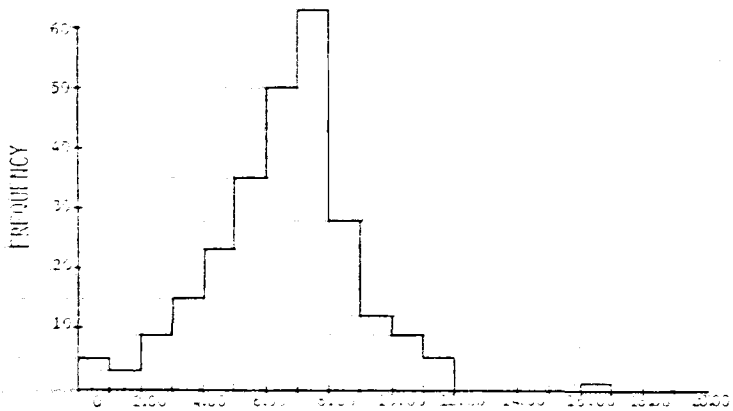



Figure 13. DISTRIBUTION OF VOLUMES PER 1 LOG TURNS, 100 BF

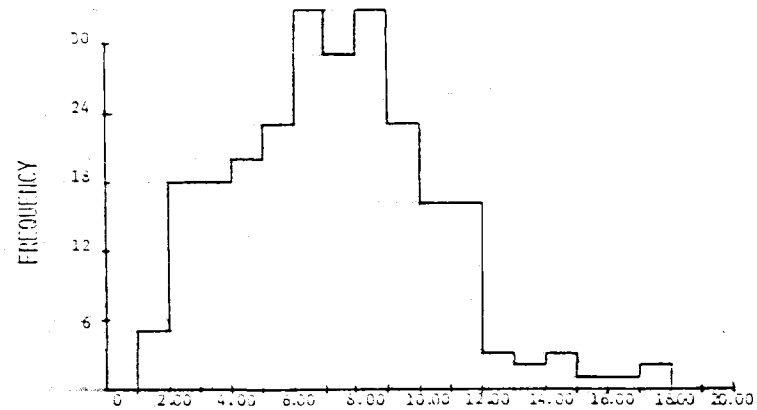



Figure 15. DISTRIBUTION OF VOLUMES PER 2 LOG TURNS, 100 BF

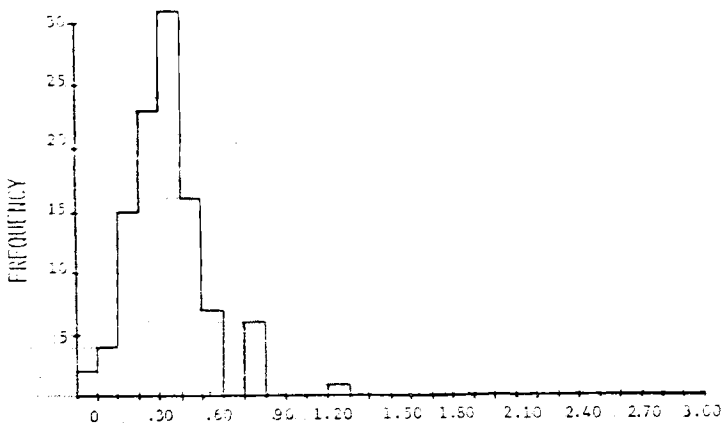



Figure 16. DISTRIBUTION OF CHOKER HOOK UP TIME, MINUTES

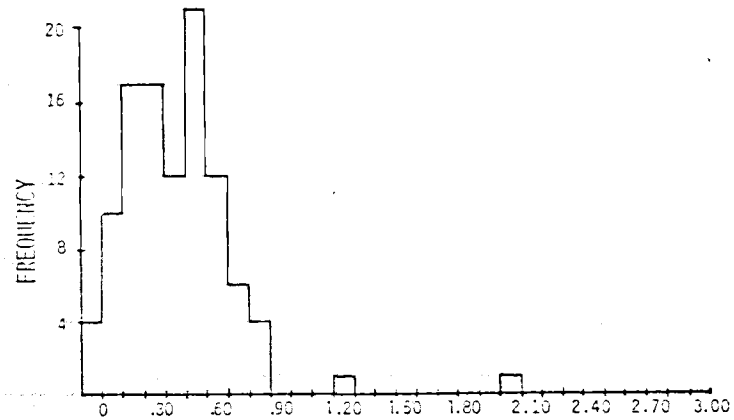



Figure 18. DISTRIBUTION OF CHOKER DELIVERY TIME, MINUTES

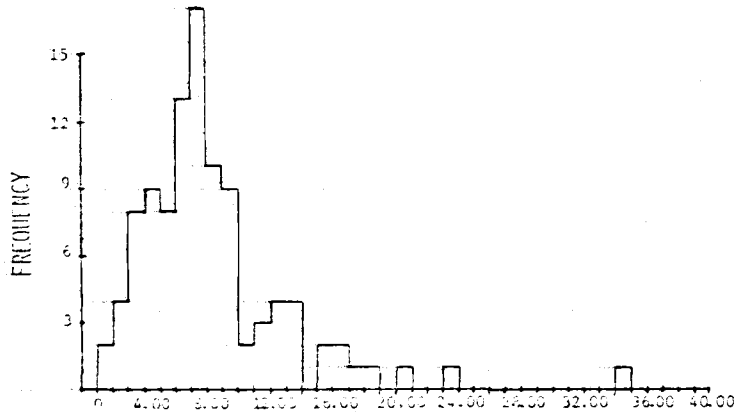



Figure 17. DISTRIBUTION OF NUMBER OF CHOKERS BETWEEN DELIVERIES

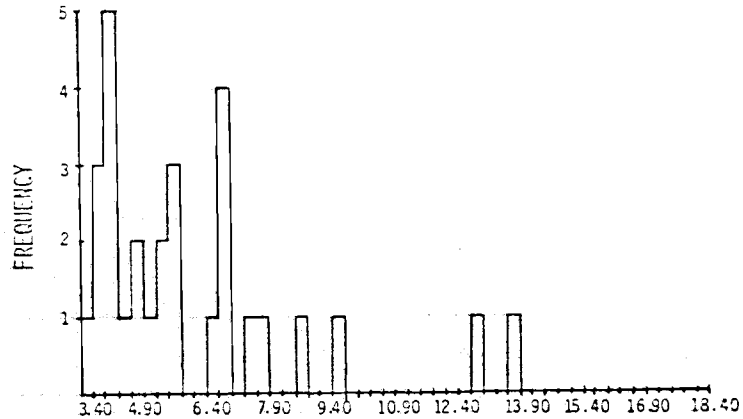



Figure 19. DISTRIBUTION OF REFUELING TIMES, MINUTES

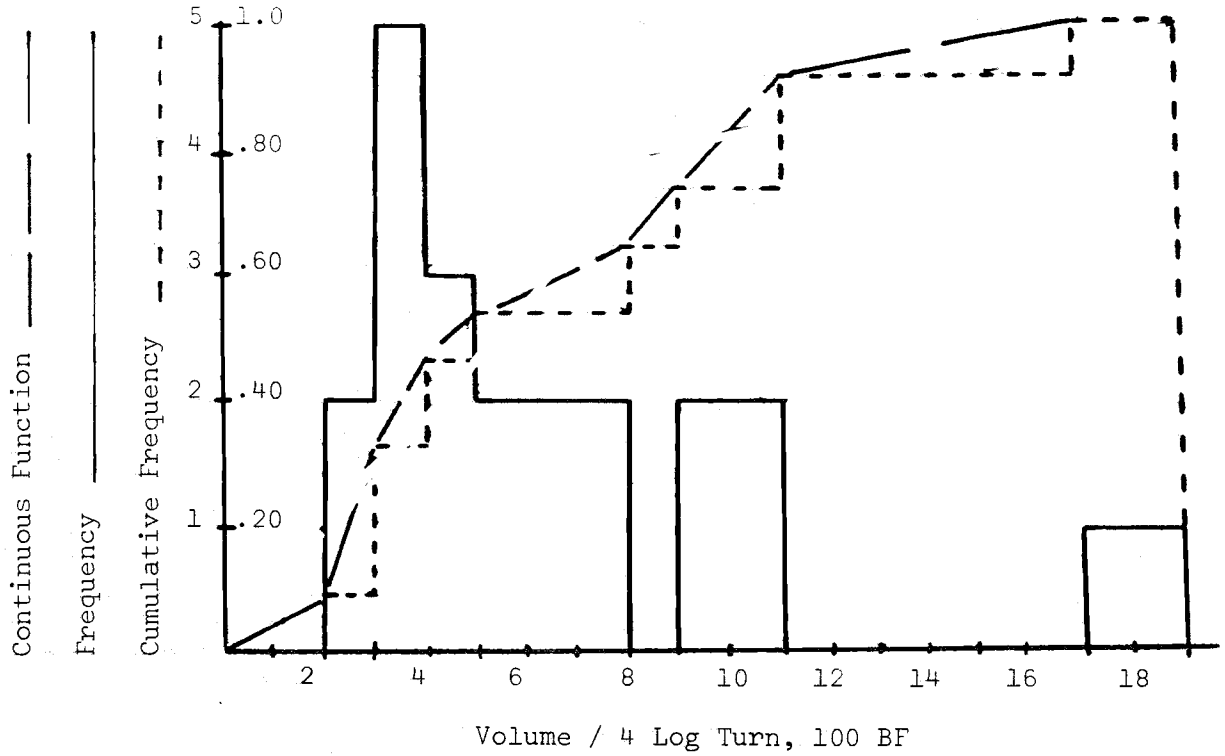



Figure 20. Conversion of Discrete Function to Continuous Function (volumes per 4 log turns, 100 BF)

## V. SIMULATION MODEL

I was interested not only in the effect of the observed relationships of variables on the yarding system, but also the effects of the unobserved relationships. It was my desire to go beyond the Universe of Observation[5]. One of the better methods that allows the above is to construct a model that will duplicate as nearly as possible the real situation and then change variables within the model to predict and observe behavior (Levin and Kirkpatrick, 1971). Simulation is a tool that allows me to accomplish this.

Simulation can be used to study response patterns of a given system under a variety of treatments. This technique, along with the use of computers, allows evaluation of many alternative actions in a short time horizon.

The computer simulation model consists of flowing through the changes in the events as they are executed. Delays, hook, and unhook are introduced through probability functions while the elements outhaul and inhaul are estimated by the regression equations.

### Flowchart of Simulation Model

The flowchart on pages 38-40 shows the flow of the simulation model. Flowchart symbols are defined according to their functions as they appear in the FORTRAN program as follows:

A - Assign tagline length, slope yarding distance, and Chord slope values for each simulated run.

[5]Observed ranges of data.

B - Check if chokers need to be hooked up for delivery to the rigging crew. A random number is generated and this value is used in subroutine (XTURNS1) to determine the number of turns that can be yarded (NXTURNS) before chokers need to be sent to the rigging crew. If this value, NXTURNS, is greater than or equal to the present number of yarded turns, the chokers will be hooked up and sent to the rigging crew. NXTURNS will change each time the choker bundles are sent out.

C - Compute the time required for the choker hook-up event. This is done by randomly selecting a time value from a continuous empirical distribution of observed choker hook-up times.

D - Compute outhaul time (TIME 8) determined in part by a given slope yarding distance and a given tagline length. The regression equation for outhaul is used.

E - Check if chokers need to be delivered to the rigging crew. This check insures that if the chokers were hooked for transport to the rigging crew, then they must be delivered to the rigging crew; otherwise proceed toward the hook-up point.

F - Compute the time required to deliver the choker bundles to the rigging crew. This is accomplished by randomly selecting a time value from a continuous empirical distribution of observed choker delivery times.

G - Compute the hook time required to hook each turn. This is done by randomly selecting a time value from a continuous empirical distribution of observed hooking times.

H - Check if the load can be lifted. The number of logs hooked per turn is again a random selection. It will, therefore, be a random selection of volume for that turn based on the number of randomly selected logs hooked. Assuming a log density of 7.33 lbs/bd ft, a check will be made to insure that the vehicle can lift the load. Otherwise, the pilot will be forced to abort the load and proceed to hook another turn and again check the lifting process.

I - If the ship aborts the load, it becomes necessary to compute a time (delay) loss. This is done by randomly selecting a time value from the continuous distribution of observed abort times.

J - The rehook time is computed at this point (randomly).

K - Compute inhaul time by means of the inhaul regression equation.

L - Compute unhook time by randomly selecting a time value from the continuous distribution of observed unhook times.

M - Compute total turn time for each turn by summing the above times.

N - Write out a summary of the cycle element times for the turn just executed.

O - Check whether the ship requires refueling. If the vehicle requires refueling, it will proceed toward the landing. The vehicle will return for another turn if it does not require refueling.

P - Compute refuel time. This is done by randomly selecting a time value from a continuous empirical distribution of observed refueling times.

Q - Write out the following statistics for a day's yarding:

1 mean total turn time

2 standard deviation

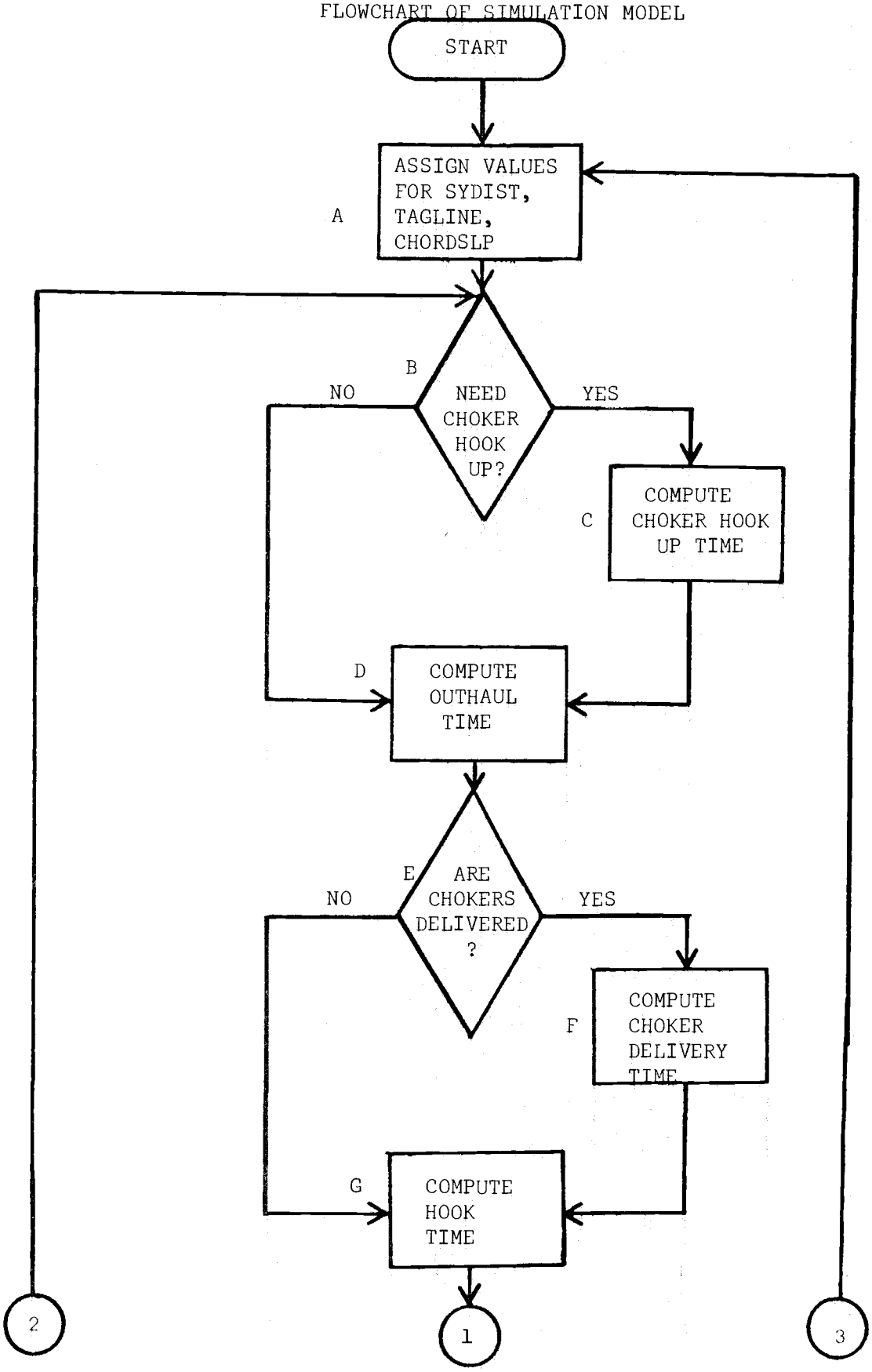
3 maximum total turn time

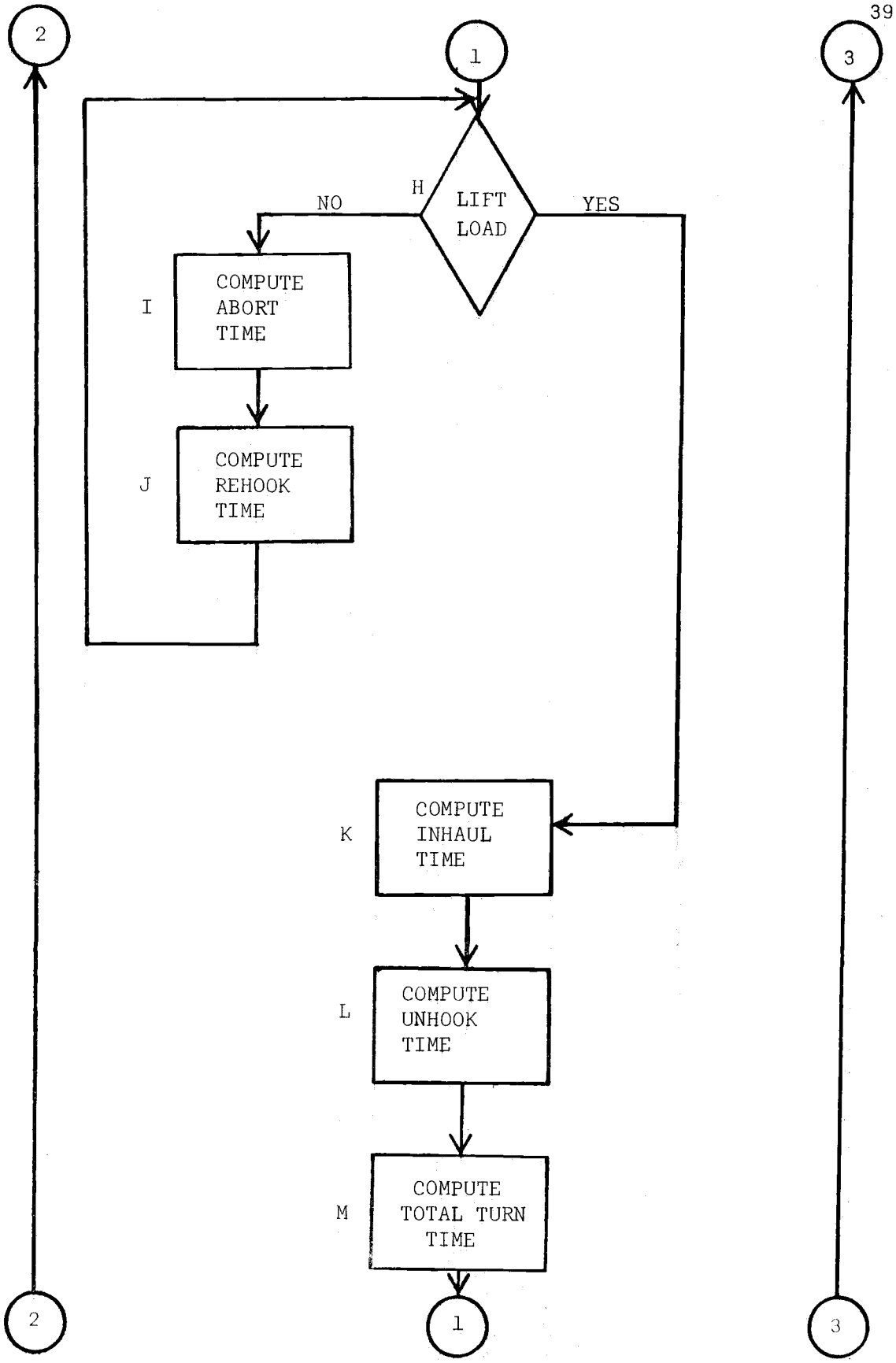
4 minimum total turn time

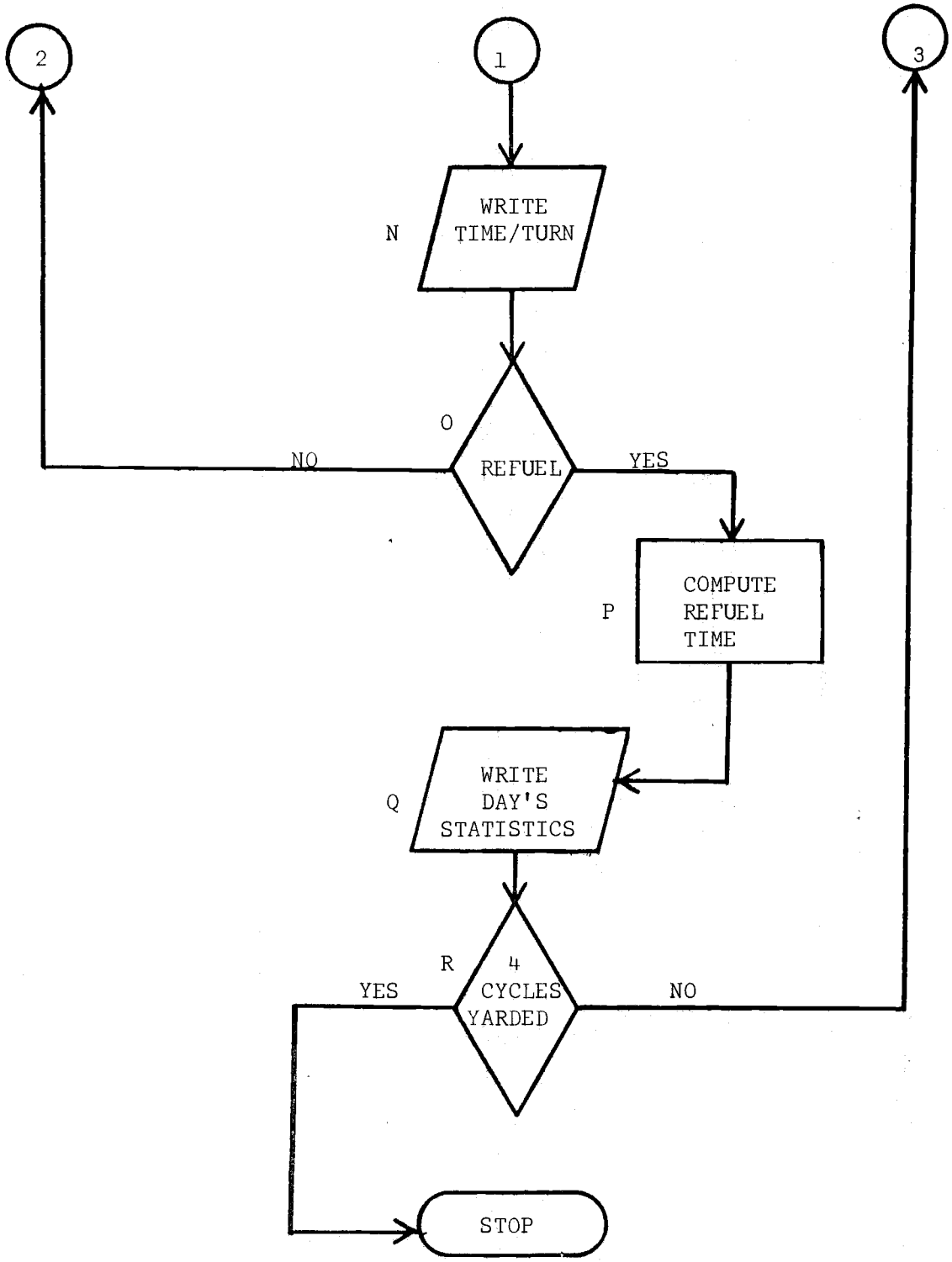
R - Check to insure that 4 cycles have been yarded. If 4 cycles have not been completed, the ship will continue to yard until 4 cycles are completed then stop. A cycle includes the number of turns yarded between refueling events.

A detailed listing of the entire FORTRAN program and its execution flow can be found in Appendix C.

FLOWCHART OF SIMULATION MODEL




2
1
3
H
LIFT LOAD
NO
YES
I
COMPUTE ABORT TIME
J
COMPUTE REHOOK TIME
K
COMPUTE INHAUL TIME
L
COMPUTE UNHOOK TIME
M
COMPUTE TOTAL TURN TIME
2
1
3


2
1
3
N
WRITE
TIME/TURN
O
NO
REFUEL
YES
P
COMPUTE
REFUEL
TIME
Q
WRITE
DAY'S
STATISTICS
R
4
CYCLES
YARDED
YES
NO
STOP

## Simulation Results

I simulated yarding from a clear-cut unit consisting primarily of old growth timber. I assumed no interruptions to the yarding system other than aborts, choker hookup, choker delivery, rehook, and refuel during a given cycle. Other assumptions are as follows:

1 That a day consists of four cycles[5a] (a cycle consists of 13 - 43 turns generated randomly).

2 That the ship will always yard for the duration of a given day.

Table 4 lists one day's production rates and element times. The detailed event by event statistics for any given day give a meaningful evaluation of production rates, delays, and element times. It becomes obvious at a glance that to evaluate each day on a turn by turn basis would be both expensive and tedious.

In an attempt to summarize relationship behavior as it influenced total turns time under varying conditions, I chose to construct a table of simulated daily times (Table 5) under the following varying conditions:

1 TAGLINE (Tagline Length) varies from 100 feet to 350 feet in increments of 50 feet.

2 SYDIST (Slope Yarding Distance) varies from 500 feet to 5000 feet in increments of 500 feet.

3 CHORDSLP (Chordslope) = 10 percent (%).

Table 4. Simulated One Day's Detailed Element Statistics

| TURN NO | HOOKUP | OUTFALL | DELIVERY | TAGLINE *100 HOOK | STDIST *1000 LOGS/TURN | CNCRESLP *10 VOL/TURN | ABORT | REHOOK | INFALL | UNHOOK | REFUEL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1.1466 | 0 | .3177 | 1 | 662 | 0 | 0 | 1.1690 | .3919 | 0 |
| 2 | 0 | 1.1466 | 0 | .3296 | 4 | 153 | 0 | 0 | 1.1546 | 0 | 0 |
| 3 | 0 | 1.1466 | 0 | .4809 | 2 | 657 | 0 | 0 | 1.1051 | 0 | 0 |
| 4 | 0 | 1.1466 | 0 | .4612 | 1 | 447 | 0 | 0 | 1.1696 | 0 | 0 |
| 5 | .2175 | 1.1466 | .5153 | .5279 | 2 | 150 | 0 | 0 | 1.0542 | .0051 | 0 |
| 6 | .1595 | 1.1466 | 0 | .6894 | 2 | 909 | 0 | 0 | 1.1176 | 0 | 0 |
| 7 | 0 | 1.1466 | 0 | 1.0505 | 1 | 1064 | 0 | 0 | 1.1380 | 0 | 0 |
| 8 | 0 | 1.1466 | 0 | .4108 | 1 | 117 | 0 | 0 | 1.0654 | .0631 | 0 |
| 9 | 0 | 1.1466 | 0 | .7658 | 1 | 1117 | 0 | 0 | 1.1411 | 0 | 0 |
| 10 | 0 | 1.1466 | 0 | .2777 | 2 | 602 | 0 | 0 | 1.1015 | 0 | 0 |
| 11 | 0 | 1.1466 | 0 | .4836 | 1 | 332 | 0 | 0 | 1.0550 | 0 | 0 |
| 12 | 0 | 1.1466 | 0 | .7291 | 2 | 311 | 0 | 0 | 1.0522 | 0 | 0 |
| 13 | 0 | 1.1466 | 0 | .1547 | 1 | 531 | 0 | 0 | 1.0555 | 0 | 0 |
| 14 | .1544 | 1.1466 | .1619 | .6941 | 1 | 476 | 0 | 0 | 1.0917 | 0 | 0 |
| 15 | .1730 | 1.1466 | 0 | .5034 | 7 | 856 | 0 | 0 | 1.1111 | 0 | 0 |
| 16 | 0 | 1.1466 | 0 | .4372 | 2 | 658 | 0 | 0 | 1.1039 | 0 | 0 |
| 17 | 0 | 1.1466 | 0 | .4556 | 7 | 610 | 0 | 0 | 1.1027 | 0 | 0 |
| TOTAL | .5244 | 19.4926 | .6797 | 8.3466 | 30 | 10136 | 0 | 0 | 16.5102 | .4621 | 4.1194 |
| MEAN | .0436 | 1.2935 | .0466 | .5564 | 2 | 609 | 0 | 0 | 1.2540 | .0100 | 0 |
| VARIANCE | .0051 | .0250 | .0191 | .0547 | 1 | 72161 | | | .0030 | .0104 | 1.1126 |
| HIGH | .1730 | 1.1466 | .5158 | 1.0505 | 4 | 1117 | 0 | 0 | 1.1431 | .3919 | 4.1194 |
| LOW | 0 | 1.1466 | 0 | .1547 | 1 | 312 | 0 | 0 | 1.0650 | 0 | 0 |
| STAN. DEV. | .0714 | .1562 | .1362 | .2312 | 1 | 269 | | | .1512 | .1018 | 1.1544 |
| C.V. % | 115.84 | 12.19 | 296.19 | 42.04 | 44 | 14 | | | 12.10 | 330.56 | 0 |
| 1 | 0 | 1.1466 | 0 | .7281 | 1 | 725 | 0 | 0 | 1.1135 | 0 | 0 |
| 2 | 0 | 1.1466 | 0 | .1919 | 1 | 1046 | 0 | 0 | 1.1404 | 0 | 0 |
| 3 | 0 | 1.1466 | 0 | 1.1040 | 2 | 1171 | 0 | 0 | 1.1725 | 0 | 0 |
| 4 | 0 | 1.1466 | 0 | .3047 | 1 | 731 | 0 | 0 | 1.1125 | 0 | 0 |
| 5 | 0 | 1.1466 | 0 | .2449 | 1 | 513 | 0 | 0 | 1.0956 | 0 | 0 |
| 6 | .2441 | 1.1466 | .1921 | .1022 | 1 | 798 | 0 | 0 | 1.1188 | 0 | 0 |
| 7 | .4652 | 1.1466 | 0 | .5109 | 2 | 645 | 0 | 0 | 1.1551 | 0 | 0 |
| 8 | 0 | 1.1466 | 0 | .5592 | 1 | 647 | 0 | 0 | 1.1078 | 0 | 0 |
| 9 | 0 | 1.1466 | 0 | .6771 | 2 | 1174 | 0 | 0 | 1.1728 | 0 | 0 |
| 10 | 0 | 1.1466 | 0 | .7617 | 2 | 435 | 0 | .0712 | 1.0551 | 0 | 0 |
| 11 | 0 | 1.1466 | 0 | .7671 | 2 | 803 | 0 | 0 | 1.1657 | 0 | 0 |
| 12 | 0 | 1.1466 | 0 | .4823 | 1 | 664 | 0 | 0 | 1.1091 | 0 | 0 |
| 13 | 0 | 1.1466 | 0 | .2129 | 4 | 716 | 0 | 0 | 1.1512 | 0 | 0 |
| 14 | 0 | 1.1466 | 0 | .2904 | 1 | 687 | 0 | 0 | 1.1108 | 0 | 0 |
| 15 | 0 | 1.1466 | 0 | .1013 | 3 | 127 | 0 | 0 | 1.1071 | 0 | 0 |
| 16 | 0 | 1.1466 | 0 | .9526 | 2 | 1177 | 0 | 0 | 1.1727 | 0 | 0 |
| TOTAL | .7033 | 18.3456 | .3923 | 6.4156 | 11 | 14191 | 0 | 0 | 17.8782 | 0 | 7.0923 |
| MEAN | .0471 | 1.2231 | .0262 | .5112 | 2 | 946 | 0 | 0 | 1.1908 | 0 | 0 |
| VARIANCE | .0104 | .0083 | .0051 | .0750 | 1 | 106518 | | | .0061 | 0 | 3.5929 |
| HIGH | .4652 | 1.1466 | .5158 | 1.1040 | 4 | 1177 | 0 | .0712 | 1.1404 | 0 | 7.0923 |
| LOW | 0 | 1.1466 | 0 | .2129 | 1 | 327 | 0 | 0 | 1.0551 | 0 | 0 |
| STAN. DEV. | .1281 | .0731 | .1705 | .2718 | 1 | 326 | | | .0781 | 0 | 1.8955 |
| C.V. % | 278.96 | 6.47 | 651.85 | 48.79 | 46 | 14 | | | 6.57 | 330.56 | 0 |
| 1 | 0 | 1.1466 | 0 | 1.1771 | 1 | 636 | 0 | 0 | 1.1159 | 0 | 0 |
| 2 | 0 | 1.1466 | 0 | .5264 | 1 | 777 | 0 | 0 | 1.1169 | .0844 | 0 |
| 3 | 0 | 1.1466 | 0 | .5064 | 1 | 608 | 0 | 0 | 1.1051 | 0 | 0 |
| 4 | 0 | 1.1466 | 0 | .9709 | 2 | 620 | 0 | 0 | 1.1010 | 0 | 0 |
| 5 | 0 | 1.1466 | 0 | .1125 | 3 | 1061 | 0 | 0 | 1.1152 | 0 | 0 |
| 6 | 0 | 1.1466 | 0 | 1.1155 | 4 | 855 | 0 | 0 | 1.1217 | .0444 | 0 |
| 7 | 0 | 1.1466 | 0 | .1021 | 1 | 576 | 0 | 0 | 1.1027 | 0 | 0 |
| 8 | 0 | 1.1466 | 0 | .5428 | 1 | 874 | 0 | 0 | 1.1243 | 0 | 0 |
| 9 | 0 | 1.1466 | 0 | .8186 | 1 | 647 | 0 | 0 | 1.1115 | 0 | 0 |
| 10 | 0 | 1.1466 | 0 | .6800 | 2 | 989 | 0 | 0 | 1.1159 | 0 | 0 |
| 11 | 0 | 1.1466 | 0 | .5959 | 2 | 665 | 0 | 0 | 1.1642 | .0806 | 0 |
| 12 | 0 | 1.1466 | 0 | .4502 | 2 | 785 | 0 | 0 | 1.1085 | 0 | 0 |
| 13 | 0 | 1.1466 | 0 | .3911 | 1 | 652 | 0 | 0 | 1.1061 | 0 | 0 |
| 14 | 0 | 1.1466 | 0 | .4507 | 1 | 538 | 0 | 0 | 1.1030 | 0 | 0 |
| 15 | 0 | 1.1466 | 0 | .7847 | 1 | 1324 | 0 | 0 | 1.1312 | 0 | 0 |
| 16 | 0 | 1.1466 | 0 | .7120 | 5 | 381 | 0 | 0 | 1.1425 | 0 | 0 |
| 17 | 0 | 1.1466 | 0 | .9429 | 2 | 655 | 0 | 0 | 1.1110 | 0 | 0 |
| 18 | 0 | 1.1466 | 0 | 1.6720 | 2 | 351 | 0 | 0 | 1.9525 | 0 | 0 |
| 19 | 0 | 1.1466 | 0 | .9953 | 1 | 805 | 0 | 0 | 1.1051 | 0 | 0 |
| 20 | 0 | 1.1466 | 0 | .5790 | 1 | 236 | 0 | 0 | 1.1045 | 0 | 0 |
| 21 | 0 | 1.1466 | 0 | .4481 | 1 | 668 | 0 | 0 | 1.1094 | 0 | 0 |
| 22 | 0 | 1.1466 | 0 | .2852 | 2 | 246 | 0 | 0 | 1.0698 | 0 | 0 |
| 23 | 0 | 1.1466 | 0 | .1632 | 2 | 274 | 0 | 0 | 1.0900 | 0 | 0 |
| 24 | 0 | 1.1466 | 0 | .5855 | 1 | 906 | 0 | 0 | 1.1710 | 0 | 0 |
| 25 | 0 | 1.1466 | 0 | .5527 | 2 | 731 | 0 | 0 | 1.0864 | 0 | 0 |
| TOTAL | 0 | 28.6654 | 0 | 16.0762 | 51 | 16671 | 0 | 0 | 27.7020 | .1797 | 6.0640 |
| MEAN | 0 | 1.1466 | 0 | .6433 | 2 | 675 | 0 | 0 | 1.1111 | .0052 | 0 |
| VARIANCE | .0113 | 0 | .0189 | .1195 | 1 | 79110 | | | .0002 | .0004 | 4.0709 |
| HIGH | .4652 | 1.1466 | .5158 | 1.6721 | 5 | 1129 | 0 | .0712 | 1.1479 | .0844 | 7.0923 |
| LOW | 0 | 1.1466 | 0 | .1021 | 1 | 231 | 0 | 0 | 1.0694 | 0 | 0 |
| STAN. DEV. | .1064 | .0000 | .1375 | .3457 | 1 | 281 | | | .0143 | .0189 | 2.0176 |
| C.V. % | 278.98 | .00 | 651.85 | 53.77 | 52 | 42 | | | 1.29 | 361.97 | 0 |
| 1 | 0 | 1.1466 | 0 | 2.2740 | 2 | 931 | 0 | 0 | 1.1138 | 0 | 0 |
| 2 | 0 | 1.1466 | 0 | .3660 | 1 | 550 | 0 | 0 | 1.1058 | .1126 | 0 |
| 3 | 0 | 1.1466 | 0 | .7046 | 1 | 790 | 0 | 0 | 1.1702 | 0 | 0 |
| 4 | 0 | 1.1466 | 0 | .6519 | 2 | 692 | 0 | 0 | 1.1051 | 0 | 0 |
| 5 | 0 | 1.1466 | 0 | .3609 | 1 | 149 | 0 | 0 | 1.0710 | 0 | 0 |
| 6 | 0 | 1.1466 | 0 | .4951 | 2 | 825 | 0 | 0 | 1.1100 | 0 | 0 |
| 7 | 0 | 1.1466 | 0 | .7091 | 2 | 813 | 0 | 0 | 1.1102 | 0 | 0 |
| 8 | 0 | 1.1466 | 0 | .1321 | 2 | 645 | 0 | 0 | 1.1035 | 0 | 0 |
| 9 | 0 | 1.1466 | 0 | .7601 | 1 | 450 | 0 | 0 | 1.0538 | 0 | 0 |
| 10 | 0 | 1.1466 | 0 | .3143 | 1 | 1027 | 0 | 0 | 1.1250 | 0 | 0 |
| 11 | 0 | 1.1466 | 0 | .6110 | 2 | 1142 | 0 | 0 | 1.1215 | 0 | 0 |
| 12 | 0 | 1.1466 | 0 | .7254 | 1 | 537 | 0 | 0 | 1.0927 | 0 | 0 |
| 13 | 0 | 1.1466 | 0 | .4844 | 3 | 1174 | 0 | 0 | 1.1273 | 0 | 0 |
| 14 | 0 | 1.1466 | 0 | .6090 | 2 | 861 | 0 | 0 | 1.1113 | 0 | 0 |
| 15 | 0 | 1.1466 | 0 | .4260 | 1 | 1094 | 0 | 0 | 1.1400 | .0557 | 0 |
| 16 | 0 | 1.1466 | 0 | .4531 | 4 | 376 | 0 | 0 | 1.1251 | 0 | 0 |
| 17 | 0 | 1.1466 | 0 | .3958 | 1 | 511 | 0 | 0 | 1.0596 | 0 | 0 |
| 18 | 0 | 1.1466 | 0 | .2606 | 1 | 628 | 0 | 0 | 1.1065 | 0 | 0 |
| 19 | 0 | 1.1466 | 0 | .3556 | 1 | 841 | 0 | 0 | 1.1221 | 0 | 0 |
| 20 | 0 | 1.1466 | 0 | .2095 | 2 | 799 | 0 | 0 | 1.1090 | 0 | 0 |
| 21 | 0 | 1.1466 | 0 | .5359 | 2 | 855 | 0 | 0 | 1.1111 | 0 | 0 |
| 22 | 0 | 1.1466 | 0 | .5552 | 2 | 547 | 0 | 0 | 1.0995 | 0 | 0 |
| 23 | 0 | 1.1466 | 0 | .2641 | 1 | 609 | 0 | 0 | 1.1051 | 0 | 0 |
| 24 | 0 | 1.1458 | 0 | .1644 | 1 | 973 | 0 | 0 | 1.1212 | 0 | 0 |
| 25 | 0 | 1.1466 | 0 | 1.0706 | 1 | 574 | 0 | 0 | 1.1025 | .0536 | 0 |
| TOTAL | 0 | 28.6654 | 0 | 13.5697 | 48 | 18571 | 0 | 0 | 27.7755 | .2722 | 1.6447 |
| MEAN | 0 | 1.1466 | 0 | .5508 | 2 | 741 | 0 | 0 | 1.1110 | .0109 | 0 |
| VARIANCE | .0113 | 0 | .0189 | .1747 | 1 | 72660 | | | .0007 | .0007 | 2.6494 |
| HIGH | .4652 | 1.1466 | .5158 | 2.2740 | 4 | 1376 | 0 | .0712 | 1.1400 | .1126 | 7.0923 |
| LOW | 0 | 1.1466 | 0 | .1323 | 1 | 149 | 0 | 0 | 1.0710 | 0 | 0 |
| STAN. DEV. | .1064 | .0000 | .1375 | .4180 | 1 | 270 | | | .0151 | .0266 | 1.6277 |
| C.V. % | 278.98 | .00 | 651.85 | 75.81 | 48 | 36 | | | 1.36 | 207.16 | 0 |

SIMULATED DAILY-TOTAL TIME-STATISTICS
SYCIDT
INCLUDES NO DELAYS

| TAGLINE | | 500 | 1000 | 1500 | 2000 | 2500 | 3000 | 3500 | 4000 | 4500 | 5000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | *A | 1.67 | 2.06 | 2.30 | 2.42 | 2.69 | 2.82 | 3.06 | 3.21 | 3.35 | 3.59 |
| | B | .34 | .34 | .43 | .32 | .46 | .23 | .55 | .30 | .26 | .46 |
| | C | 3.57 | 3.65 | 4.61 | 3.79 | 4.94 | 3.54 | 5.39 | 4.40 | 4.54 | 6.26 |
| | D | 1.39 | 1.56 | 1.65 | 1.97 | 2.16 | 2.40 | 2.57 | 2.76 | 2.93 | 3.14 |
| 150 | A | 1.79 | 1.96 | 2.12 | 2.31 | 2.55 | 2.75 | 2.92 | 3.06 | 3.41 | 3.48 |
| | B | .37 | .39 | .40 | .39 | .39 | .38 | .28 | .30 | .44 | .30 |
| | C | 3.20 | 3.94 | 4.56 | 4.35 | 4.27 | 4.45 | 3.92 | 4.45 | 5.84 | 4.91 |
| | D | 1.30 | 1.49 | 1.69 | 1.88 | 2.04 | 2.26 | 2.47 | 2.66 | 2.95 | 3.06 |
| 200 | A | 1.68 | 1.86 | 2.00 | 2.22 | 2.48 | 2.60 | 2.80 | 2.97 | 3.23 | 3.36 |
| | B | .33 | .33 | .37 | .31 | .43 | .28 | .26 | .31 | .36 | .32 |
| | C | 3.07 | 2.87 | 4.09 | 3.63 | 4.87 | 3.71 | 4.03 | 4.71 | 4.77 | 5.17 |
| | D | 1.26 | 1.46 | 1.59 | 1.80 | 1.97 | 2.16 | 2.31 | 2.60 | 2.73 | 2.91 |
| 250 | A | 1.56 | 1.76 | 1.88 | 2.06 | 2.37 | 2.59 | 2.71 | 2.95 | 3.09 | 3.25 |
| | B | .49 | .40 | .30 | .21 | .39 | .39 | .40 | .38 | .43 | .29 |
| | C | 4.42 | 4.30 | 3.84 | 2.66 | 4.66 | 4.26 | 5.62 | 5.34 | 5.95 | 4.41 |
| | D | 1.09 | 1.37 | 1.48 | 1.65 | 1.85 | 2.14 | 2.29 | 2.49 | 2.65 | 2.78 |
| 300 | A | 1.51 | 1.59 | 1.81 | 2.01 | 2.21 | 2.45 | 2.55 | 2.80 | 2.93 | 3.22 |
| | B | .43 | .38 | .29 | .49 | .31 | .42 | .23 | .48 | .26 | .36 |
| | C | 3.36 | 3.17 | 3.24 | 4.64 | 3.54 | 4.15 | 3.18 | 5.68 | 4.35 | 4.80 |
| | D | .94 | 1.26 | 1.43 | 1.56 | 1.80 | 1.95 | 2.14 | 2.34 | 2.52 | 2.85 |
| 350 | A | 1.36 | 1.62 | 1.72 | 1.96 | 2.16 | 2.27 | 2.48 | 2.70 | 2.87 | 3.07 |
| | B | .32 | .48 | .34 | .45 | .34 | .33 | .27 | .34 | .37 | .30 |
| | C | 2.75 | 4.40 | 4.26 | 4.32 | 3.48 | 3.51 | 3.50 | 4.09 | 5.53 | 4.37 |
| | D | .87 | 1.10 | 1.32 | 1.47 | 1.73 | 1.86 | 2.03 | 2.22 | 2.45 | 2.60 |

CHORDSLP= 10%

* A = Mean Turn Time
B = Standard Deviation
C = Maximum Turn Time
D = Minimum Turn Time

Table 5. Simulated Mean (Daily) Total Turn Times
Delays Omitted

For each treatment (days time), the mean turn time, the standard deviation, maximum and minimum values were computed and listed vertically in placement of occurrences on the table. For example, for a tagline length of 100 feet, a SYDIST (Slope yarding distance) of 2500 feet, and a CHORDSLP (Chordslope) of 10 percent, a MEAN daily total turn time of 2.69 minutes with a STANDARD DEVIATION of .46 minutes was realized. The MAXIMUM value of total turn time was 4.94 minutes with a MINIMUM value of 2.16 minutes. The previous statistics allow a good estimate of the vehicle's efficiency on a given day under given conditions.

The same set of conditions as above was simulated once again introducing the observed delays. Table 6 lists the helicopter's efficiency statistics as affected by the introduction of delays. Table 7 lists a comparison of simulated turn times (delays included and delays omitted).

Although the percent delay time observed in Table 7 seems a small percentage, it is important to remember that this small percentage is a percentage of the mean total turn time. Viewed in this light, delay time becomes an important factor.

SIMULATED DAILY-TOTAL TIME-STATISTICS
SYDIST
INCLUDES ALL DELAYS

| TAGLINE | | 500 | 1000 | 1500 | 2000 | 2500 | 3000 | 3500 | 4000 | 4500 | 5000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | * A | 1.90 | 2.16 | 2.37 | 2.51 | 2.80 | 2.67 | 3.16 | 3.29 | 3.42 | 3.74 |
| | B | .36 | .42 | .53 | .37 | .62 | .31 | .63 | .38 | .38 | .71 |
| | C | 3.57 | 3.85 | 4.81 | 4.05 | 5.48 | 3.95 | 5.89 | 4.26 | 4.88 | 7.95 |
| | D | 1.39 | 1.58 | 1.85 | 2.01 | 2.16 | 2.40 | 2.59 | 2.76 | 2.93 | 3.14 |
| 150 | A | 1.88 | 2.01 | 2.21 | 2.35 | 2.63 | 2.84 | 3.04 | 3.14 | 3.45 | 3.53 |
| | B | .52 | .43 | .49 | .41 | .43 | .46 | .49 | .43 | .47 | .33 |
| | C | 4.19 | 3.94 | 4.56 | 4.35 | 4.27 | 5.16 | 5.73 | 4.90 | 5.84 | 4.91 |
| | D | 1.30 | 1.49 | 1.69 | 1.55 | 2.04 | 2.28 | 2.47 | 2.66 | 2.85 | 3.06 |
| 200 | A | 1.79 | 1.93 | 2.06 | 2.34 | 2.57 | 2.67 | 2.84 | 3.04 | 3.33 | 3.46 |
| | B | .44 | .43 | .40 | .59 | .51 | .35 | .32 | .39 | .54 | .43 |
| | C | 3.47 | 3.83 | 4.09 | 6.23 | 4.87 | 3.85 | 4.03 | 4.71 | 6.52 | 5.17 |
| | D | 1.28 | 1.48 | 1.59 | 1.80 | 1.97 | 2.16 | 2.31 | 2.60 | 2.73 | 2.91 |
| 250 | A | 1.66 | 1.81 | 1.94 | 2.13 | 2.45 | 2.70 | 2.79 | 3.07 | 3.14 | 3.32 |
| | B | .57 | .49 | .39 | .32 | .46 | .55 | .51 | .64 | .46 | .35 |
| | C | 4.42 | 4.72 | 3.84 | 3.48 | 4.88 | 5.14 | 5.62 | 7.40 | 5.95 | 4.41 |
| | D | 1.09 | 1.37 | 1.46 | 1.65 | 1.85 | 2.14 | 2.29 | 2.46 | 2.65 | 2.80 |
| 300 | A | 1.59 | 1.79 | 1.83 | 2.09 | 2.32 | 2.53 | 2.62 | 2.92 | 2.99 | 3.33 |
| | B | .51 | .66 | .30 | .50 | .40 | .50 | .36 | .60 | .38 | .50 |
| | C | 3.69 | 4.85 | 3.24 | 4.64 | 3.54 | 4.15 | 4.48 | 5.68 | 5.03 | 5.15 |
| | D | .94 | 1.27 | 1.43 | 1.56 | 1.81 | 1.95 | 2.14 | 2.34 | 2.52 | 2.85 |
| 350 | A | 1.42 | 1.69 | 1.76 | 2.00 | 2.23 | 2.32 | 2.57 | 2.73 | 2.92 | 3.15 |
| | B | .38 | .55 | .37 | .43 | .41 | .36 | .40 | .53 | .42 | .43 |
| | C | 2.75 | 4.40 | 4.16 | 4.32 | 4.18 | 3.51 | 4.65 | 5.57 | 5.53 | 6.08 |
| | D | .87 | 1.10 | 1.32 | 1.47 | 1.73 | 1.86 | 2.03 | 2.22 | 2.45 | 2.60 |

CHORDSLP= 10%

*A = Mean Turn Time
B = Standard Deviation
C = Maximum Turn Time
D = Minimum Turn Time

Table 6. Simulated Mean (Daily) Total Turn Times Delays Included

COMPARISON OF SIMULATED DAILY TOTAL TURN TIMES

SLOPE YARDING DISTANCE (Feet)

| Tagline (feet) | | 3000 Delays Included | 3000 Delays omitted | 3000 % Delay Time | 5000 Delays included | 5000 Delays omitted | 5000 % Delay Time |
|---|---|---|---|---|---|---|---|
| 100 | Mean | 2.87 | 2.82 | 1.74 | 3.74 | 3.59 | 4.01 |
| | Standard dev. | .31 | .23 | - | .71 | .46 | - |
| | Maximum | 3.95 | 3.54 | - | 7.95 | 6.26 | - |
| | Minimum | 2.40 | 2.40 | - | 3.14 | 3.14 | - |
| 300 | Mean | 2.53 | 2.45 | 3.16 | 3.33 | 3.22 | 3.30 |
| | Standard dev. | .50 | .42 | - | .50 | .36 | - |
| | Maximum | 4.15 | 4.15 | - | 5.15 | 4.80 | - |
| | Minimum | 1.95 | 1.95 | - | 2.85 | 2.85 | - |

CHORDSLOPE = 10%

Table 7. Comparison of total turn times, delays included and delays omitted (simulated times).

# VI. SUMMARY AND CONCLUSIONS

I analyzed the yarding system of a Boeing-Vertol 107 Model II helicopter. Operations were observed under a wide range of conditions. Using data that was gathered during the summer of 1973, I employed regression techniques and simulation principles. The yarding system was broken down into the following components:

Outhaul Time

Hook Time

Inhaul Time

Unhook Time

The delays for which enough data was gathered were defined as:

Abort Time

Rehook Time

Choker Hook-up Time

Choker Delivery Time

Regression equations were derived to estimate productive times for the cycle elements, outhaul and inhaul. For the other elements and delays, frequency distributions were used as estimates of probability density functions. A paired t-test of the equations established their ability to predict the element times. The equations, along with the frequency distributions, were used to simulate total time for this yarding system.

The entire analysis is based on a single helicopter yarding system. To further test the data, other studies should be conducted both in old growth and second growth stands to better understand the variables and their relationships as they affect the yarding system. Further studies should include other variables. Weight per turn is a variable that should be considered in much detail. Individual pilot performance, along with individual hooker performance, should also be considered. Finally, a detailed study of the delay types and their occurrence would be very meaningful in further analyzing this yarding system.

The computer simulation model was developed in FORTRAN. This model can be used to study daily event-by-event behavior or a daily day-by-day behavior to a given treatment (set of yarding conditions). I constructed a table of simulated total turn time on a given day for each of 60 different days. This table included all delays. A delay-free simulated table was also constructed to study the effects of the yarding delays. This comparison led to the following recommendations of system modifications that might be implemented and tested.

1) A smaller model helicopter might be used to deliver the chokers to the rigging crew instead of the larger yarding vehicle. This should result in a time savings. This smaller vehicle might also be used to yard smaller materials.

2) The hooker might, to a large degree, reduce the rehook delay by insuring that the choker eye(s) are properly placed inside

the hook mechanism before giving the signal to lift off.

3) The abort delay might be eliminated by properly estimating log weights to insure more uniform loads. This might be accomplished by sampling log weights in the units to be yarded and expressing this weight value to some measurable form such as DBH and length. The faller(s) could then tag or mark the logs in some form that would enable the hooker to select a proper turn.

Construction of similar simulated tables would be of great importance to an operator. The operator could (given the independent variables characteristic of a unit to be logged) simulate similar tables to predict production rates, efficiency and delay times.

The model would also prove valuable to the forest manager in planning unit layouts. Managers could evaluate given units utilizing the model as an aid in appraising timber sales for yarding costs, delay allowances, and production rates.

If aerial logging is to become fully competitive with other logging systems, much work remains to be done in isolating factors and delays that result in time loss during the yarding cycle. Removal of second-growth timber by helicopter requires a detailed look. If helicopter logging is to be used as an efficient forestry tool, the forester's knowledge of the influencing factors is one requirement.

Footnotes

3a

Chaser - the individual responsible for removing the chokers from the logs as they arrive at the landing, also responsible for bundling the chokers.

5a Cycle - A cycle consists of the yarding time involved between refueling events.

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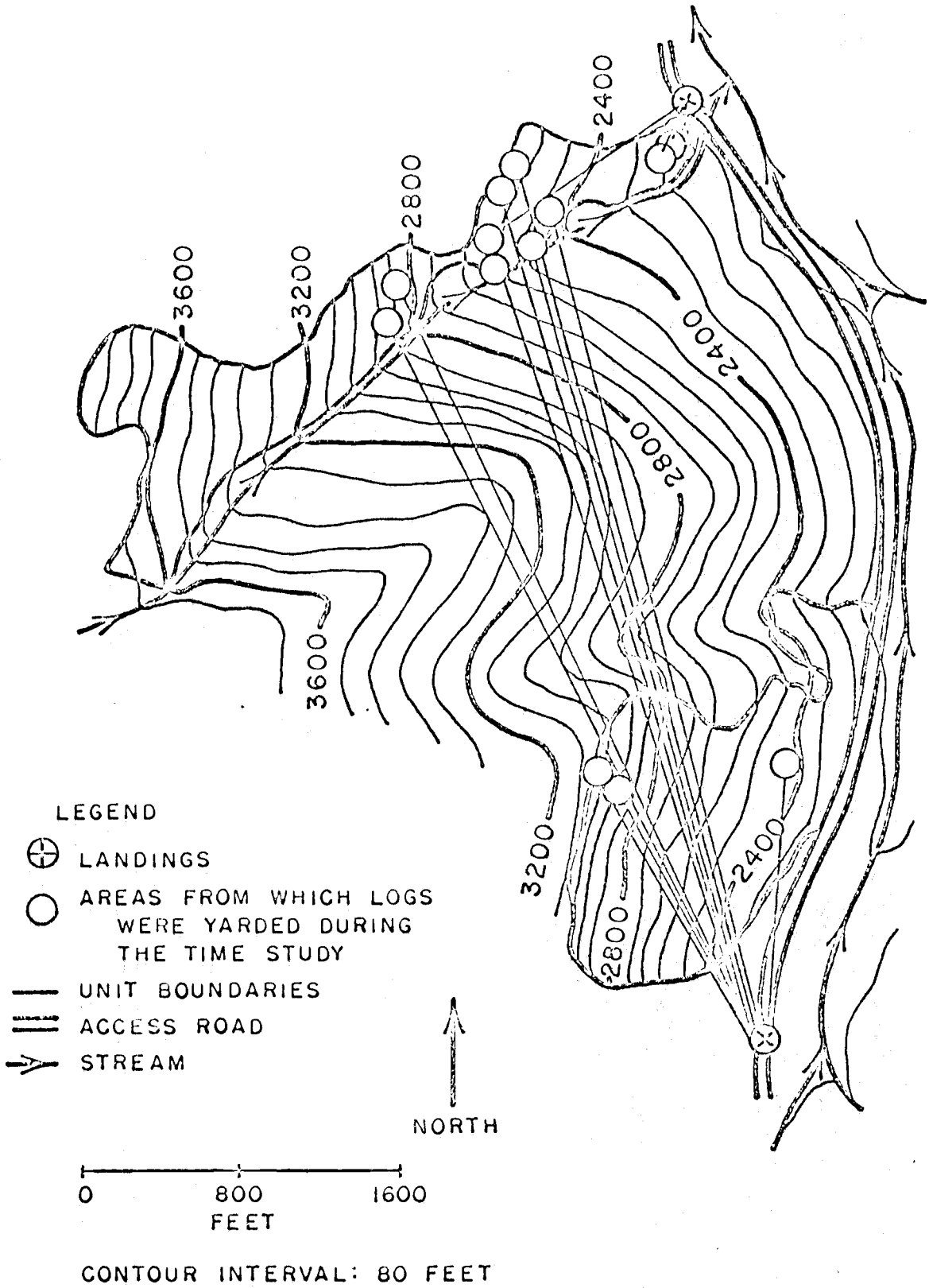
# APPENDIX A

## CAMELSBACK TIMBER SALE (UNIT MAP)




* Map courtesy of Dennis Dykstra (1974).

# APPENDIX B

## OBSERVED POSITIONING OF THE HELICOPTER

## OBSERVED POSITIONING OF THE HELICOPTER

Diagram 1 shows a flowchart of the ship traveling a hypothetical flight path. At point number 3 the ship is being positioned directly over the hook up point. The ship approaches the hook up point in the indicated direction and then proceeds to hover over the desired point (number 3 through 6) until the turn has been hooked and the hooker has moved to a safe position. The ship yet remains to be turned around facing the landing before the turn is lifted in proceeding toward the landing (number 7). Much the same series of events occur at the landing. The ship arrives at the landing (number 8) and proceeds to unhook. It is not until the turn has been released that the ship begins to reposition itself before returning to the hook up point.

Although I have no quantitative data to support the flow indicated in Diagram 2, it appears that this ship could begin to reposition itself as it approached the hook up point and the landing as shown by the flowchart[6]. The positioning before arriving at the landing or hook up would serve two purposes. It might serve to reduce total turn time, increasing production and aid in reducing fuel consumption. I believe this is an area that needs more attention. Again, I have no quantitive proof of this situation and recommend that this be investigated further in another study.

---

[6](Ahnstrom, 1968) The wind has little effect on this vehicle (the Vertol has two horizontal rotors). This minimizes the wind effect while, for example, the S64E helicopter has one large main horizontal rotor and a small rear vertical rotor. This one vertical rotor would present positioning problems due to wind resistance on this rotor.

Diagram 1. OBSERVED POSITIONING FLOWCHART

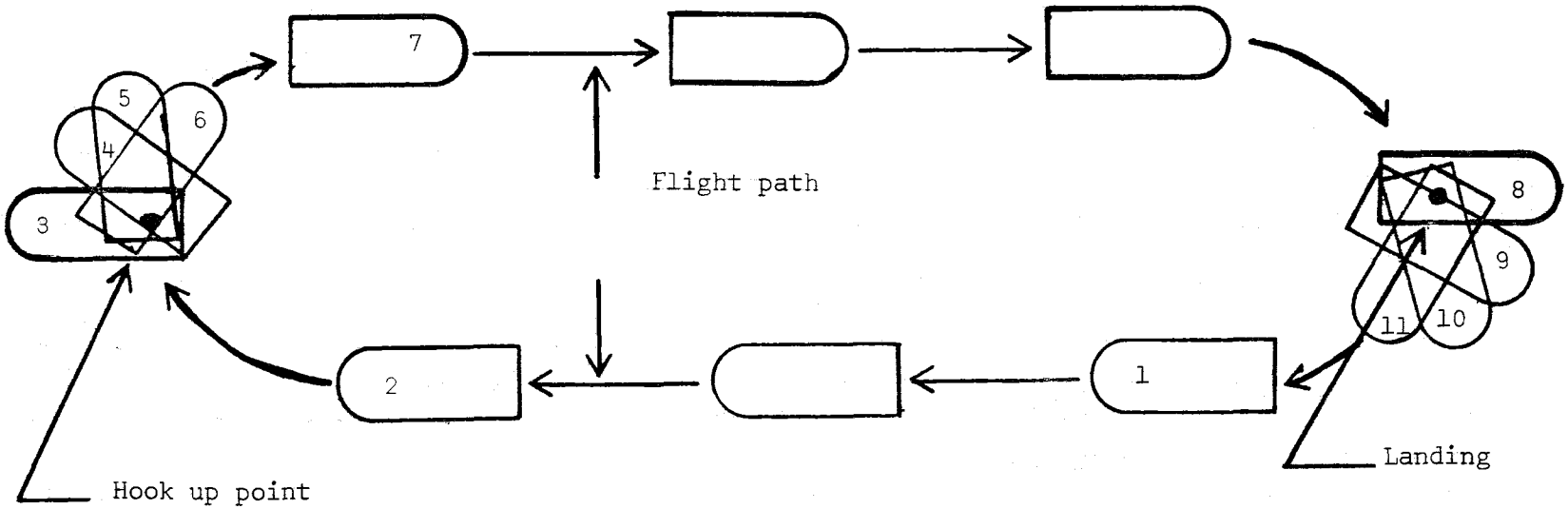
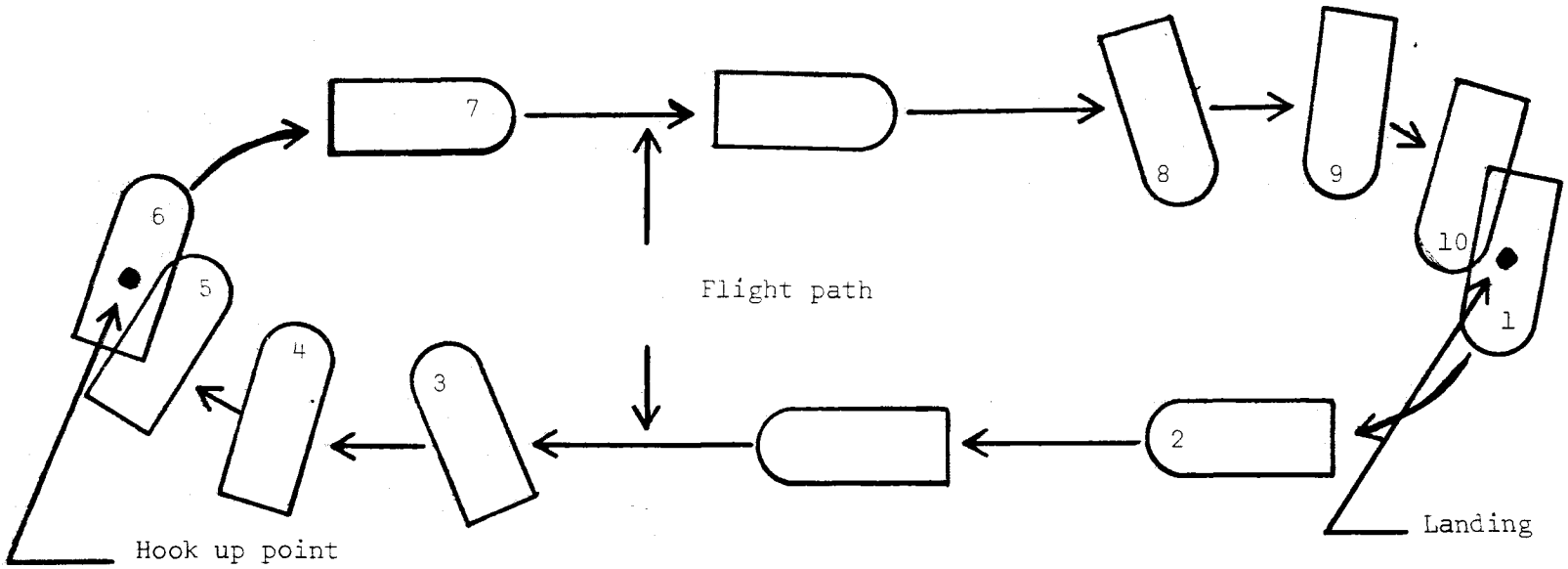


Diagram 2. POSSIBLE IMPROVEMENT IN FLIGHT PATTERN FLOWCHART



# APPENDIX C

## FORTRAN SIMULATION PROGRAM LISTING

```
      PROGRAM SIMULATE
C...
C...  MAIN PROGRAM SIMULATE IS THE CALLING PROGRAM FOR A SERIES
C...  OF SUBROUTINES WHICH DEFINE THE SELECTION OF A RANDOM
C...  NUMBER AND WITH THIS VALUE ENTER A TABLE OF FREQUENCIES
C...  TO DETERMINE A GIVEN VALUE FOR A CYCLE ELEMENT OR TO BE
C...  EMPLOYED IN AN EQUATION REPRESENTING A CYCLE ELEMENT
C...  TO SIMULATE THE YARDING OPERATION OF A BOEING-
C...  VERTOL 107  MODEL II HELICOPTER.
C...
C...  THE FORTRAN PROGRAM WAS DEVELOPED FOR
C...   A CDC 3300.
C...
C...  TO RUN ON THE OSU OS-3 OPERATING SYSTEM:
C...     EQUIP,5=FILE
C...     EQUIP,6=FILE
C...     EQUIP,7=FILE
C...     ≥FORTRAN,I=SIMULATE,R
C...
C...
C...  THE PROGRAM CONSISTS OF THE FOLLOWING COMPONENTS:
C...  SUBROUTINES ARE LISTED BELOW:
C...
C...     (1)  MAIN PROGRAM SIMULATE- CALLS SUBROUTINES AND
C...          MAINTAINS COMPLETE CONTROL OF THE ENTIRE EXECUTION
C...          (THE LOGIC FOR THE ENTIRE EXECUTION IS ALSO INCLUD
C...          -ED).
C...
C...     (2)  SUBROUTINE RANDOM - COMPUTES A PSEUDO RANDOM
C...          NUMBER TO BE USED IN THE RESPECTIVE SUBROUTINE.
C...
C...     (3)  SUBROUTINE ABORT2- ENTERS THE  CONTINUOUS
C...          CUMULATIVE DENSITY FUNCTION FOR THE DURATION OF
C...          ABORT DELAYS WITH A UNIFORMLY DISTRIBUTED RANDOM
C...          VARIATE FROM "RANDOM" AND RETURNS A VALUE FOR THE
C...          DURATION OF AN ABORT DELAY.
C...
C...     (4)  SUBROUTINE REHOOK2- ENTERS THE CONTINUOUS
C...          CUMULATIVE DENSITY FUNCTION FOR THE DURATION OF
C...          REHOOK DELAYS WITH A UNIFORMLY DISTRIBUTED RANDOM
C...          VARIATE FROM "RANDOM" AND RETURNS A VALUE FOR
C...          THE DURATION OF THE REHOOK DELAY.
C...
C...     (5)  SUBROUTINE UNHOOK2- ENTERS THE CONTINUOUS
C...          CUMULATIVE DENSITY FUNCTION FOR THE DURATION OF
C...          UNHOOK TIMES WITH A UNIFORMLY DISTRIBUTED RANDOM
C...          VARIATE FROM "RANDOM" AND RETURNS A VALUE FOR THE
C...          DURATION OF THAT UNHOOKING EVENT.
C...
C...     (6)  SUBROUTINE REFUEL2 - ENTERS THE CONTINUOUS
C...          CUMULATIVE DENSITY FUNCTION FOR THE DURATION OF
C...          REFUELING EVENTS WITH A UNIFORMLY DISTRIBUTED
C...          RANDOM VARIATE FROM "RANDOM" AND RETURNS
C...          A VALUE FOR THE DURATION OF EACH REFUELING EVENT.
C...
C...     (7)  SUBROUTINE LOGS2 - RANDOMLY SELECTS A GIVEN TURN
C...          SIZE ( 1 THROUGH 6 LOGS/TURN) FROM A DISCRETE
C...          CUMULATIVE DENSITY FUNCTION.
C...
C...     (8)  SUBROUTINE VOLUME2 - ENTERS THE CONTINUOUS
C...          CUMULATIVE DENSITY FUNCTION FOR THE VOLUMES
C...          OBSERVED WITH A UNIFORMLY DISTRIBUTED RANDOM
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C...          VARIATE FROM 'RANDOM' AND RETURNS A VALUE FOR THE
C...          VOLUME OF THAT TURN.  THE CDF ENTERED IS FOR THE
C...          NUMBER OF LOGS RETURNED BY 'LOGS2'.
C...
C...     (9)  SUBROUTINE OUTHAUL - COMPUTES AN OUTHAUL TIME
C...          FROM A REGRESSION EQUATION UTILIZING TAGLINE
C...          LENGTH AND SLOPE YARDING DISTANCE.
C...
C...    (10)  SUBROUTINE INHAUL - COMPUTES AN INHAUL TIME
C...          FROM A REGRESSION EQUATION UTILIZING SLOPE
C...          YARDING DISTANCE,CHORDSLOPE,NUMBER OF LOGS
C...          PER TURN,TAGLINE LENGTH,AND VOLUME PER LOG.
C...
C...    (11)  SUBROUTINE CHOKC2 - ENTERS THE CONTINUOUS
C...          CUMULATIVE DENSITY FUNCTION FOR THE DURATION OF
C...          CHOKER HOOKUP DELAYS WITH A UNIFORMLY DISTRIBUTED
C...          RANDOM VARIATE FROM 'RANDOM' AND
C...          RETURNS A VALUE FOR THE DURATION OF EACH CHOKER
C...          HOOKUP DELAY.
C...
C...    (12)  SUBROUTINE HOOK2 - ENTERS THE CONTINUOUS
C...          CUMULATIVE DENSITY FUNCTION FOR THE DURATION
C...          OF  HOOK TIMES WITH A UNIFORMLY DISTRIBUTED
C...          RANDOM VARIATE FROM 'RANDOM' AND RETURNS A VALUE
C...          FOR THE DURATION OF THAT HOOKING EVENT.
C...
C...    (13)  SUBROUTINE CHOKI2 - ENTERS THE CONTINUOUS
C...          CUMULATIVE DENSITY FUNCTION FOR THE DURATION OF
C...          CHOKER DELIVERY TIMES WITH A UNIFORMLY DISTRIBUTED
C...          RANDOM VARIATE FROM 'RANDOM' AND RETURNS A VALUE
C...          FOR THE DURATION OF THAT CHOKER DELIVERY DELAY.
C...
C...    (14)  SUBROUTINE STATS - COMPUTES THE MEAN, VARIANCE,
C...          STANDARD DEVIATION, COEFFICIENT OF VARIATION,
C...          MAXIMUM AND MINIMUM VALUES FOR  AN ARRAY.
C...
C...    (15)  SUBROUTINE XTURNS1 - ENTERS A CONTINUOUS
C...          CUMULATIVE DENSITY FUNCTION FOR THE NUMBER
C...          OF TURNS THAT MUST BE YARDED BEFORE A CHOKER
C...          HOOKUP EVENT OCCURS.  A UNIFORMLY DISTRIBUTED
C...          RANDOM VARIATE FROM 'RANDOM' IS USED TO DETERMINE
C...          THE VALUE OF THE CHOKER HOOKUP DELAY.
C...
C...    (16)  SUBROUTINE XTURNS2 - ENTERS THE CONTINUOUS
C...          CUMULATIVE DENSITY FUNCTION FOR THE DURATION OF
C...          REFUELING EVENTS WITH A UNIFORMLY DISTRIBUTED
C...          RANDOM VARIATE FROM 'RANDOM' AND RETURNS A VALUE
C...          THAT WILL DETERMINE THE FREQUENCY OF REFUELING
C...          EVENTS.
C...
C...     TABLE OF NOMENCLATURE
C...
C...  VARIABLES ARE DEFINED AS THEY OCCUR.
C...
C...     (1)  TURN - NUMBER OF TURNS YARDED
C...
C...     (2)  NTURNS - COUNTER FOR FILLING ARRAYS - NO. OF
C...          TURNS YARDED PER CYCLE
C...
C...     (3)  NCYC - COUNTER FOR TERMINATION OF ONE DAYS RUN
C...          - NO. OF CYCLES EXECUTED
C...
C...     (4)  TNLOGS - ACCUMULATOR FOR TOTAL LOGS YARDED
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C...
C...     (5)  TXVOLUME - ACCUMULATOR FOR TOTAL VOLUME YARDED
C...
C...     (6)  NTURNS1 - COUNTER FOR CHOKER HOOK UP AND
C...                    DELIVERY - NO. OF TURNS YARDED BETWEEN
C...                    TIMES OF CHOKER HOOK UP FOR DELIVERY
C...
C...     (7)  NADD - COUNTER FOR FILLING ARRAYS
C...                - NO. OF TURNS YARDED PER DAY
C...
C...     (8)  NSYDIST - COUNTER FOR NESTED DO LOOP
C...                   --NO. OF YARDING DISTANCES EXECUTED
C...
C...     (9)  NTAG - COUNTER FOR DO LOOP
C...                - NO. OF TAGLINE EXECUTIONS
C...
C...    (10)  ABORTS3 - ARRAY CONTAINING ABORT-DELAY TIMES
C...
C...    (11)  REHOOK3 - ARRAY CONTAINING REHOOK- DELAY TIMES
C...
C...    (12)  REFUEL3 - ARRAY CONTAINING REFUEL-DLEAY TIMES
C...
C...    (13)  NXTURNS - NO. OF TURNS BETWEEN CHOKER HOOK UP AND
C...          DELIVERYS (NO. OF TURNS THAT MUST BE YARDED
C...          BETWEEN CHOKER HOOKUP AND CHOKER DELIVERY EVENTS).
C...
C...    (14)  XTURNS3  - NO. OF TURNS BETWEEN REFUEL EVENTS
C...
C...    (15)  HOOKUP - ARRAY CONTAINING CHOKER HOOKUP TIMES
C...
C...    (16)  OUTHAUL1 - ARRAY CONTAINING OUTHAUL TIMES
C...
C...    (17)  DELIVERY - ARRAY CONTAINING CHOKER DELIVERY TIMES
C...
C...    (18)  HOOK3 - ARRAY CONTAINING HOOK TIMES
C...
C...    (19)  LOGS3 - ARRAY CONTAINING LOGS YARDED/TURN
C...
C...    (20)  VOLUME3 - ARRAY CONTAINING VOLUME YARDED/TURN
C...
C...    (21)  INHAUL1 - ARRAY CONTAINING INHAUL TIMES
C...
C...    (22)  UNHOOK3 - ARRAY CONTAINING UNHOOK TIMES
C...
C...    (23)  TIME1 - CHOKER HOOK UP TIME
C...
C...    (24)  TIME2 - OUTHAUL TIME
C...
C...    (25)  TIME3 - CHOKER DELIVERY TIME
C...
C...    (26)  TIME4 - HOOK TIME
C...
C...    (27)  TIME6 - ABORT TIME
C...
C...    (28)  TIME7 - REHOOK TIME
C...
C...    (29)  TIME8 - INHAUL TIME
C...
C...    (30)  TIME9 - UNHOOK TIME
C...
C...    (31)  TIME10 - REFUEL TIME
C...
C...    (32)  TIME11 - TIME REQUIRED TO HOOK UP CHOKERS FOR
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C...                    DELIVERY DURING REFUELING PROCESS
C...
C...    (33)  TTIME1 - TOTAL CHOKER HOOK UP TIME
C...
C...    (34)  TTIME2 - TOTAL OUTHALL TIME
C...
C...    (35)  TTIME3 - TOTAL CHOKER DELIVERY TIME
C...
C...    (36)  TTIME4 - TOTAL HOOK TIME
C...
C...    (37)  TTIME6 - TOTAL ABORT TIME
C...
C...    (38)  TTIME7 - TOTAL REHOOK TIME
C...
C...    (39)  TTIME8 - TOTAL INHAUL TIME
C...
C...    (40)  TTIME9 - TOTAL UNHOOK TIME
C...
C...    (41)  TTIME10 - TOTAL REFUEL TIME
C...
C...    (42)  TTIME11 - TOTAL TIME REQUIRED TO HOOK UP CHOKERS
C...                    DURING REFUELING PROCESS
C...
C...    (43)  MEAN3 - ARRAY CONATAINING DAILY-TOTAL MEANS
C...                  PER TREATMENT
C...
C...    (44)  STDEV3 - ARRAY CONTAINING DAILY-TOTAL STANDARD
C...                   DEVIATIONS
C...
C...    (45)  XHIGH22 - ARRAY CONTAINING DAILY-TOTAL MAXIMUM
C...                    VALUES PER TREATMENT
C...
C...    (46)  XLOW22 - ARRAY CONTAINING DAILY-TOTAL MINIMUM
C...                   VALUES PER TREATMENT
C...
C...    (47)  XCELL - ARRAY CONTAINING TURN TIMES
C...
C...    (48)  TTIME - TOTAL TURN TIMES
C...
C...  THE PROGRAM WILL SIMULATE ONE DAY'S YARDING FOR EACH OF
C...  SIXTY TREATMENTS.  A DETAILED LISTING OF INDIVIDAUL EVENT
C...  STATISTICS FOR EACH TREATMENT ARE PRINTED ALONG
C...  WITH THE STATISTICS FOR EACH TREATMENT (TOTAL
C...  TIMES) ON A DAILY BASIS.**NOTICE** - THIS PRODUCES A
C...  MASSIVE AMOUNT OF OUTPUT AND IS EXPENSIVE.  ONE CAN
C...  ELIMINATE THE DETAILED EVENT BY EVENT STATISTICS AND
C...  CHOOSE TO ANAYLIZE THE DAILY TOTALS AS TREATMENTS,
C...  THIS RESULTS IN LESS OUTPUT AND LESS EXPENSE.
C...
C...  APPENDIX      HAS A SUMMARY OF BOTH DETAILED DAYS
C...  STATISTICS ALONG WITH A COMPLETE SUMMARY OF SIXTY DAILY
C...  TREATMENTS (MEAN, STANDARD DEVIATION, MAXIMUM AND MINIMUM
C...  VALUES FOR ANY GIVEN DAILY TREATMENT).
C...
C...
      REAL LOGS,LOGS1,LOGS3,INHAUL1
C...
C...  DIMENSION ALL ARRAYS AND THEIR SISTER ARRAYS THAT
C...  CONTAIN ABSCISSA VALUES (TIMES) CORRESPONDING TO
C...  EACH CUMULATIVE DENSITY FUNCTION VALUE.  OTHER
C...  ARRAYS CONTAIN DETAILED ELEMENT AND CYCLE TIMES AND
C...  PRODUCTIONS RATES WHICH ARE LATER USED IN COMPUTING
C...  STATISTICS FOR EACH EVENT.
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C...
      DIMENSION CHOKO(9),CHOKO1(9),HOOK(26),HOOK1(26)
     1,HOOKLF(45),OUTHAUL1(45),DELIVERY(45) ,HOOK3(45),
     1LOGS3(45),VOLUME3(45),ABORT3(45),REHOOK3(45),
     1INHAUL1(45),UNHOOK3(45),REFUEL3(45),LOGS(6),
     1LOGS1(6),CHOKI(11),CHOKI1(11),ABORT(18),ABORT1(18),
     1REHOOK(8),REHOOK1(8),UNHOOK(10),UNHOOK1(10),
     1REFUEL(16),REFUEL1(16),IR(11),IA(11),IC(11),
     1VOLUME(6,102),VOLUME1(6,102),REFUEL4(16),
     1REFUEL5(16),CHOKI4(20),CHOKI5(20),
     1XCELL(150),XMEAN3(10),STDEV3(10),XHIGH22(10),XLOW22(10),
     1SYDIST(10),TAGLINE(6)
C...
C...  DATA STATEMENTS ARE USED TO INITIALIZE CUMULATIVE
C...  DENSITY FUNCTIONS FOR EMPIRICAL DISTRIBUTIONS.
C...  ABSCISSA VALUES ARE ALSO ENTERED CORRESPONDING TO EACH
C...  CDF VALUE IN A SISTER ARRAY.
C...
      DATA((CHOKO(I),I=1,9)=.0191,.0575,.2000,.4190,.7142,.8666
     1,.9333,.9904,1.0)
      DATA((CHOKO1(I),I=1,9)=0.,.1,.2,.3,.4,.5,.6,.8,1.2)
      DATA((HOOK(I),I=1,26)=.0032,.0417,.1605,.3461,.5302,.6679
     1,.7774,.8876,.9175,.9357,.9571,.9614,.9588,.9763,.9817,.9
     1828,.9848,.9892,.9902,.9912,.9924,.9935,.9945,.9967,.9988
     1,1.0)
      DATA((HOOK1(I),I=1,26)=.1,.2,.3,.4,.5,.6,.7,.8,1.0,1.
     11,1.2,1.4,1.5,1.6,1.7,1.8,1.9,2.0,2.2,2.3,2.4,2.5,2.9,3.0
     1,3.2,3.5)
      DATA((LOGS(I),I=1,6)=.3886,.7730,.9454,.9903,.9946,1.0)
      DATA((LOGS1(I),I=1,6)=1.0,2.0,3.0,4.0,5.0,6.0)
      DATA((CHOKI(I),I=1,11)=.0381,.1333,.2952,.4571,.5714,.771
     14,.8857,.9429,.9809,.9904,1.0)
      DATA((CHOKI1(I),I=1,11)=0.,.1,.2,.3,.4,.5,.6,.7,.8,1.2
     1,2.0)
      DATA((ABORT(I),I=1,18)=.0465,.0691,.0931,.1396,.1861,
     1.3256,.4419,.5116,.6511,.8134,.8367,.8600,.8833,.9036,
     1.9299,.9532,.9765,1.0)
      DATA((ABORT1(I),I=1,18)=0.,.1,.2,.5,.6,.7,.8,1.0,1.1,1.2,
     11.5,1.6,1.7,1.9,2.3,2.7,3.0,4.0)
      DATA((REHOOK(I),I=1,8)=.1667,.2500,.3333,.4166,.6666,.833
     16,.9166,1.0)
      DATA((REHOOK1(I),I=1,8)=.4,.6,.7,.8,1.0,1.3,1.6,3.0)
      DATA((UNHOOK(I),I=1,10)=.8169,.9454,.9786,.9882,.9935,.99
     146,.9957,.9978,.9989,1.0)
      DATA((UNHOOK1(I),I=1,10)=0.,.1,.2,.3,.4,.5,.6,.7,1.2,1.5)
      DATA((REFUEL(I),I=1,16)=.0345,.1379,.3104,.3448,.4138,.44
     182,.5173,.6207,.6551,.7931,.8276,.8621,.8965,.9310,.9655,
     11.0)
      DATA((REFUEL1(I),I=1,16)=3.4,3.7,4.0,4.3,4.6,4.9,5.2,5.5,
     16.4,6.7,7.3,7.6,8.5,9.4,12.7,13.6)
      DATA(((VOLUME(NLOGS,I),I=1,17),NLOGS=1,6
     1)=.0194,.0310,.0659,.1239,.2131,.3487,.5425,
     1.7867,.8952,.9417,.9764,.9957,1.0,1.0,1.0,1.0,
     11.0,.0203,.0935,.1667,.2480,.3415,.4756,.5935,.7277,
     1.8212,.8862,.9512,.9634,.9716,.9838,.9878,.9919,
     11.0,.0185,.0833,.2222,.3704,.4723,.6112,.6760,
     1.8149,.8990,.9075,.9260,.9634,1.0,1.0,1.0,1.0,1.0,.0909
     1,.3182,.4546,.5455,.6364,.7273,.8182,.9091,.9495,
     11.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,.3333,.6666,1.0,
     11.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,
     11.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,
     11.0,1.0,1.0,1.0,1.0)
      DATA(((VOLUME1(NLOGS,I),I=1,17),NLOGS=1,6)=100.,200.,
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      1300.,400.,500.,600.,700.,800.,900.,1000.,1100.,1200.,
      11700.,0.,0.,0.,0.,200.,300.,400.,500.,600.,700.,
      1800.,900.,1000.,1100.,1200.,1300.,1400.,1500.,1600.,
      11700.,1800.,200.,300.,400.,500.,600.,700.,800.,900.,
      11000.,1100.,1200.,1300.,1400.,1500.,1500.,1500.,
      11500.,300.,400.,500.,600.,700.,800.,1000.,1100.,
      11800.,1900.,1900.,1900.,1900.,1900.,1900.,1900.,1900.,
      1200.,400.,500.,500.,500.,500.,500.,500.,500.,
      1500.,500.,500.,500.,500.,500.,500.,500.,500.,500.,
      1500.,500.,500.,500.,500.,500.,500.,500.,500.,
      1500.,500.,500.,500.,500.,500.)
       DATA((IR(I),I=1,11)=81376,129745,689076,500000,833884,876
      1613,548612,777777,645213,666666,88888)
       DATA((IA(I),I=1,11)=2069,2069,2085,2085,4117,4117,4133,413
      13,2069,2069,2085)
       DATA((IC(I),I=1,11)=1772721,6615877,1772721,6615877,
      11772721,6615877,1772721,6615877,1772721,6615877,
      11772721)
       DATA((CHOKI4(I),I=1,20)=.0196,.0588,.1372,.2255,.3039,
      1.4313,.5930,.6960,.7842,.8036,.8332,.8721,.9116,.9319,
      1.9506,.9604,.9702,.9800,.9898,1.0)
       DATA((CHOKI5(I),I=1,20)=2.0,3.0,4.0,5.0,6.0,7.0,8.0,9.0,
      110.0,11.0,12.0,13.0,14.0,16.0,17.0,18.0,19.0,21.0,24.0,
      135.0)
       DATA((REFUEL4(I),I=1,16)=.1666
      1,2333,.2666,.3333,.3666,.5332,.5666,.5999,.6332,.
      17332,.7999,.8332,.8665,.8999,.9665,1.0)
       DATA((REFUEL5(I),I=1,16)=13.0,14.0,16.0,
      117.0,18.0,20.0,21.0,22.0,23.0,24.0,25.0,26.0,34.0,
      135.0,40.0,43.0)
       DATA((SYDIST(I),I=1,10)=500.,1000.,1500.,2000.,2500.,
      13000.,3500.,4000.,4500.,5000.)
       DATA((TAGLINE(I),I=1,6)=100.,150.,200.,250.,300.,350.)
C...
C...   INITIALIZE TIMES FOR  EXECUTION
C...
       TURN=0
       NTURNS=0
       TTIME1=0
       TTIME2=0
       TTIME3=0
       TTIME4=0
       TTIME6=0
       TTIME7=0
       TTIME8=0
       TTIME9=0
       TTIME10=0
       TTIME11=0
       TTIME=0
       TIME=0
       NCYC=0
       TNLOGS=0
       NTURNS=0
       TXVOLUME=0
       NTURNS1=0
       NADD=0
C...
C...
C...   INITIALIZE CHCRDSLP TO 10 PERCENT AND HOLD THIS VALUE
C...   CONSTANT DURING THE ENTIRE EXECUTION.  THIS VARIABLE
C...   WAS CHOSEN TO BE HELD CONSTANT DUE TO ITS SMALL CONT-
C...   RIBUTION TO TOTAL TIME.
C...
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      CHORDSLP=10.
      WRITE(6,777)
  777 FORMAT(≠1≠)
      WRITE(6,444)
C...
C...  WRITE HEADINGS FOR DETAILED CYCLE ELEMENT TIMES AND
C...  PRODUCTION RATES.
C...
  444 FORMAT(47X,≠SIMULATED DAILY-TOTAL TIME-STATISTICS≠)
      WRITE(6,445)
  445 FORMAT(63X,≠SYDIST≠)
      WRITE(6,446)
  446 FORMAT(14X,113(≠*≠))
      WRITE(6,887)(SYDIST(I),I=1,10)
      WRITE(6,447)
  447 FORMAT(14X,113(≠*≠))
C...
C...  THIS NTAG - DO LOOP VARIES THE TAGLINE LENGTH FROM 100
C...  FEET TO 350 FEET IN INCREMENTS OF 50 FEET.
C...
      DO 8889 NTAG=1,6
      DO 8888 NSYDIST=1,10
C...
C...  THIS NSYDIST - DO LOOP VARIES THE SYDIST FROM 500
C...  TO 5000 IN INCREMENTS OF 500 FEET.  AFTER EACH TAGLINE
C...  LENGTH IS TREATED WITH SYDIST, IT WILL JUMP OUT OF
C...  THIS LOOP AND CONTINUE EXECUTION UNTIL ALL TAGLINES HAVE
C...  EXPERIENCED THE SAME TREATMENT.
C...
      DO 16 I=1,25
      ABORT3(I)=0
      REHOOK3(I)=0
      REFUEL3(I)=0
   16 CONTINUE
C...
C...  WRITE  HEADINGS FOR DETAILED CYCLE ELEMENT TIMES
C...  AND PRODUCTION RATES.
C...
      WRITE(5,801)TAGLINE(NTAG),SYDIST(NSYDIST),CHORDSLP
  801 FORMAT(1H1,45X,≠TAGLINE =≠,F3.0,2X,≠SYDIST =≠,F4.0,2X,
     1≠CHORDSLP =≠,F2.0)
      WRITE(5,800)
  800 FORMAT(12X,≠TURN NO≠,2X,≠HOOKUP≠,2X,≠OUTHAUL≠,2X,
     1≠DELIVERY≠,5X,≠HOOK≠,2X,≠LOGS/TURN≠,2X,≠VOL/TURN≠,
     12X,≠ABORT≠,2X,≠REHOOK≠,2X,≠INHAUL≠,10X,≠UNHOOK≠,10X,
     1≠REFUEL≠)
 4000 NTURNS1=0
      CALL RANDOM(IR,IA,IC,U,10)
C...
C...  THE USER SHOULD DELETE THE FOLLOWING STATEMENT IF HE
C...  DOES NOT WISH TO HAVE THE RANDOM NUMBERS LISTED.
C...
      WRITE(7,9500)U
 9500 FORMAT(E16.6)
      CALL XTURNS1(U,CHOKI4,CHOKI5,NXTURNS)
      IF(TURN.LT.XTURNS3)GO TO 3000
C...
C...  GENERATE A RANDOM NUMBER TO ENTER THE TABLES.
C...
 6000 CALL RANDOM(IR,IA,IC,U,11)
      TURN=0
C...
C...  AGAIN ONE MAY WISH TO DELETE THE FOLLOWING STATEMENT
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C...  IF HE DOES NOT WISH TO LIST MORE RANDOM NUMBERS.
C...
      WRITE(7,9500)U
C...
C...  UPON EXECUTION OF THIS ROUTINE THE
C...  NUMBER WHICH DETERMINES THE FREQUENCY OF REFUELING
C...  OCCURENCES WILL BE RETURNED.  THIS NUMBER WILL CHANGE
C...  EVERY TIME THE HELICOPTER REFUELS.
C...
      CALL XTURNS2(U,REFUEL4,REFUEL5,XTURNS3)
C...
C...  THIS STATEMENT WILL WRITE OUT THE NUMBER OF TURNS THAT
C...  MUST BE EXECUTED BEFORE  THE SHIP HAS TO SEND
C...  CHOKERS TO THE RIGGING CREW OR REFUEL RESPECTIVELY.
C...
 3000 WRITE(7,2000)NXTURNS,XTURNS3
 2000 FORMAT(I3,F3.0)
  500 NTURNS=NTURNS+1
      NTURNS1=NTURNS1+1
C...
C...  THIS STATEMENT CHECKS TO SEE IF NTURNS1 - THE
C...  NUMBER OF TURNS YARDED  AGAINST
C...  THE NUMBER OF TURNS THAT CAN OCCUR BEFORE THE CHOKERS
C...  ARE AGAIN READY TO BE SENT TO THE RIGGING CREW
C...  ( BUNDLED IN 20 TO 30 PER BUNDLE).
C...
      IF(NTURNS1.GE.NXTURNS)GO TO 140
C...
C...  IF THE CHOKERS ARE READY TO BE HOOKED THEN A CHOKERS
C...  HOOK UP EVENT WILL OCCUR AND IT WILL TRANSFER COMMAND
C...  TO STATEMENT 150.
C...
      GO TO 150
C...
C...  GENERATE A RANDOM NUMBER.
C...
  140 CALL RANDOM(IR,IA,IC,U,1)
C...
C...  THIS SUBROUTINE WILL ACCESS THE CUMULATIVE DENSITY
C...  FUNCTION OF CHOKER HOOKUP TIMES AND WILL RETURN A
C...  VALUE THAT WILL BE THE DURATION OF THAT
C...  DELAY.
C...
      CALL CHOKO2(U,TIME1,CHOKO,CHOKO1)
      TTIME1=TTIME1+TIME1
      HOOKUP(NTURNS)=TIME1
C...
C...  THIS ROUTINE WILL COMPUTE THE OUTHAUL TIME REQUIRED FOR
C...  THE VEHICLE TO TRAVEL THE GIVEN DISTANCE SYDIST
C...  AND WITH A GIVEN TAGLINE LENGTH.
C...
  150 CALL OUTHAUL(TAGLINE(NTAG),SYDIST(NSYDIST),TIME2)
      TTIME2=TTIME2+TIME2
      OUTHAUL1(NTURNS)=TIME2
C...
C...  THIS STATEMENT AGAIN CHECKS TO SEE IF CHOKERS HAVE BEEN
C...  PICKED UP AT THE LANDING ARE TO BE TRANSPORTED TO
C...  THE RIGGING CREW.  IF THEY NEED TO BE DELIVERED A
C...  TIME (TIME3) WILL BE COMPUTED BASED ON THE RANDOM
C...  NUMBER SUPPLIED IN THE PREVIOUS RANDOM NUMBER CALL.
C...
      IF(NTURNS1.GE.NXTURNS)GO TO 100
      GO TO 600
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C...
C...  IF THE CHOKERS DO NOT REQUIRE ATTENTION THE SHIP WILL
C...  PROCEED  TOWARD THE HOOKER ENABLING HIM TO
C...  HOOK ANOTHER TURN.
C...
 100  CALL RANDOM(IR,IA,IC,U,2)
      CALL CHOKI2(L,TIME3,CHOKI,CHOKI1)
      TTIME3=TTIME3+TIME3
      DELIVERY(NTURNS)=TIME3
C...
C...  GENERATE ANOTHER RANDOM NUMBER,
C...
 600  CALL RANDOM(IR,IA,IC,U,3)
C...
C...
      CALL HOOK2(U,TIME4,HOOK,HOOK1)
C...
C...  THE ABOVE ROUTINE COMPUTES A HOOK TIME BASED ON
C...  THE ABOVE RANDOM NUMBER.
C...
      TTIME4=TTIME4+TIME4
      HOOK3(NTURNS)=TIME4
 700  CONTINUE
C...
C...  GENERATE A RANDOM NUMBER.
C...
      CALL RANDOM(IR,IA,IC,U,4)
C...
C...  USING THE ABOVE RANDOM NUMBER COMPUTE THE NUMBER OF
C...  LOGS TO HOOK THAT PARTICULAR TURN.
C...
      CALL LOGS2(U,NLOGS,LOGS,LOGS1)
      TNLOGS=TNLOGS+NLOGS
      LOGS3(NTURNS)=NLOGS
C...
C...  GENERATE ANOTHER RANDOM NUMBER.
C...
      CALL RANDOM(IR,IA,IC,U,5)
C...
C...
      CALL VOLUME2(U,NLOGS,VOLUME,VOLUME1,XVOLUME)
C...
C...  EMPLOYING THE ABOVE RANDOM NUMBER AGAIN SELECT A
C...  GIVEN VOLUME DETERMINED IN PART BY THAT RANDOM
C...  NUMBER AND THE NUMBER OF LOGS HOOK PREVIOUSLY FOR
C...  THAT TURN.
C...
      TXVOLUME=TXVOLUME+XVOLUME
      VOLUME3(NTURNS)=XVOLUME
C...
C...  THIS STATEMENT CHECKS THE VOLUME JUST COMPUTED
C...  AND CHECKS IT AGAINST A VOLUME OF 1500 BOARD FEET
C...  ( ROUGHLY 8,000 POUNDS WEIGHT ) TO SEE IF THE SHIP
C...  CAN LIFT THIS LOAD, IF IT CAN NOT LIFT THE LOAD IT
C...  IS FORCED TO ABORT.
C...
C...  IF AN ABORT OCCURS CONTROL IS TRANSFERED TO STATEMENT
C...  60 WHERE THE COMPUTATION OF THE DELAY DURATION IS MADE.
C...
      IF(XVOLUME.GE.1500.) GO TO 50
C...
      GO TO 60
C...
```

```
   50  CALL RANDOM(IR,IA,IC,U,6)
       CALL ABORT2(U,TIME6,ABORT,ABORT1)
       ABORT3(NTURNS)=TIME6
       TTIME6=TTIME6+TIME6
C...
C...   GENERATE A RANDOM NUMBER AND THEN PROCEED TO COMPUTE
C...   A REHOOK TIME IF A REHOOK DELAY IS TO OCCUR.
C...
       CALL RANDOM(IR,IA,IC,U,7)
       CALL REHOOK2(U,TIME7,REHOOK,REHOOK1)
       REHOOK3(NTURNS)=TIME7
C...
C...   AT THIS POINT THE HELICOPTER WAS FORCED TO ABORT THE
C...   LOAD.   SINCE A NEW TURN IS TO BE HOOKED WE TRANSFER
C...   CONTROL TO STATEMENT 700 WHICH IS DESCRIBED ABOVE.
C...
       GO TO 700
C...
   60  CONTINUE
C...   IF THE HELICOPTER CAN SUCCESSFULLY LIFT THE LOAD, THEN
C...   STATEMENT 60 WILL BE EXECUTED AND THE SHIP WILL PROCEED
C...   TOWARD THE LANDING.
C...
C...
C...   WE MUST COMPUTE AN INHAUL TIME.  INHAUL TIME IS COMPUTED
C...   AS DEPENDENT ON THE NLOGS,SYDIST,CHORDSLP,TAGLINE,AND
C...   XVOLUME.
C...
       CALL INHAUL(NLOGS,SYDIST(NSYDIST),CHORDSLP,TAGLINE(NTAG),X
      1VOLUME,TIME8)
C...
       TTIME8=TTIME8+TIME8
       INHAUL1(NTURNS)=TIME8
       CALL RANDOM(IR,IA,IC,U,8)
       CALL UNHOOK2(U,TIME9,UNHOOK,UNHOOK1)
       TTIME9=TTIME9+TIME9
       UNHOOK3(NTURNS)=TIME9
       TURN=TURN+1
C...
C...   COMPUTE TOTAL TURN TIME FOR EACH TURN.
C...
       TIME=TIME1+TIME2+TIME3+TIME4+TIME6+TIME7+TIME8
      1+TIME9
       TTIME=TTIME+TIME
       NADD=NADD+1
       XCELL(NADD)=TIME
C...
C...   WRITE OUT ALL DETAILED ELEMENT TIMES AND PRODUCTION
C...   RATES ON A PER TURN BASIS.
C...
       WRITE(5,400)TURN,TIME1,TIME2,TIME3,TIME4,
      1NLOGS,XVOLUME,TIME6,TIME7,TIME8,TIME9,TIME10
C...
C...   REINITIALIZE TIMES FOR FURTHER EXECUTION.
C...
       TIME1=0
       TIME3=0
       TIME10=0
       TIME7=0
       TIME6=0
C...
C...   THIS STATEMENT CHECKS THE NUMBER OF TURNS YARDED
C...   AGAINST THE NUMBER OF TURNS REQUIRED BEFORE THE
```

```
C...  SHIP HAS TO REFUEL.  IF IT HAS TO REFUEL THEN THE
C...  SHIP WILL PROCEED TO REFUEL, CALLING THE REFUEL2
C...  SUBROUTINE TO CALCULATE TIME10 -REFUEL TIME.  IF
C...  THE SHIP DOES NOT REFUEL IT WILL CHECK TO INSURE
C...  THAT CHOKERS DO NOT NEED DELIVERY TO
C...  RIGGING CREW.  IF THE CHOKERS DO NEED DELIVERING IT WILL
C...  PROCEED TO DELIVER THEM, IF NOT  IT WILL  PROCEED
C...  TOWARD ANOTHER TURN.
C...
      IF(TURN.GE.XTURNS3)GO TO 80
C...
      IF(NTURNS1.GE.NXTURNS)GO TO 4000
C...
      GO TO 500
   80 CALL RANDOM(IR,IA,IC,U,9)
      CALL REFUEL2(U,TIME10,REFUEL,REFUEL1)
      REFUEL3(NTURNS)=TIME10
      TTIME10=TTIME10+TIME10
C...
C...  THIS STATEMENT CHECKS TO SEE IF CHOKERS ARE BEING HOOKED
C...  DURING THE REFUELING OPERATION.  IF THEY DO NEED
C...  TO BE HOOKED AT THIS TIME THE TIME ASSIGNED TO
C...  THIS IS ZERO DUE TO THE FACT THAT IT DID NOT REQUIRE
C...  ADDITIONAL TIME.
C...
      IF(NTURNS1.GE.NXTURNS)GO TO 90
      WRITE(5,1000)
 1000 FORMAT(20X,112(*+*))
C...
C...  AT THIS POINT THE TOTALS FOR THAT COMPLETED CYCLE ARE
C...  WROTE OUT.  THE CALL STATS STATMENTS BELOW  SERVE
C...  TO COMPUTE SOME SIMPLE STATISTICS FOR EACH
C...  DETAILED EVENT AND FOR THE ENTIRE CYCLE.
C...
      WRITE(5,900)TTIME1,TTIME2,TTIME3,TTIME4,TNLOGS,
     1TXVOLUME,TTIME6,TTIME7,TTIME8,TTIME9,TTIME10
  900 FORMAT(5X,*TOTAL*,9X,F7.4,1X,F7.4,1X,F7.4,6X,F7.4,6X,F3.0
     1,2X,F7.0,2X,F7.4,1X,F7.4,3X,F7.4,9X,F7.4,8X,F7.4)
 4000 FORMAT(16X,F3.0,1X,F6.4,2X,F6.4,2X,F6.4,7X,F6.4,7X,I2,4X,F
     15.0,3X,F6.4,2X,F6.4,4X,F6.4,10X,F6.4,9X,F6.4)
      CALL STATS(HOOKUP,NTURNS,TTIME1,XMEAN1,VAR1,HIGH1,XLOW1
     1,SD1,CVPCT1)
      CALL STATS(OUTHAUL1,NTURNS,TTIME2,XMEAN2,VAR2,HIGH2,
     1XLOW2,SD2,CVPCT2)
      CALL STATS(DELIVERY,NTURNS,TTIME3,XMEAN3,VAR3,HIGH3,XLOW3
     1,SD3,CVPCT3)
      CALL STATS(HOOK3,NTURNS,TTIME4,XMEAN4,VAR4,HIGH4,XL
     1OW4,SD4,CVPCT4)
      CALL STATS(LOGS3,NTURNS,TNLOGS,XMEAN5,VAR5,HIGH5,XLOW5,
     1SD5,CVPCT5)
      CALL STATS(VOLUME3,NTURNS,TXVOLUME,XMEAN11,VAR11,HIGH11,
     1XLOW11,SD11,CVPCT11)
      CALL STATS(ABORT3,NTURNS,TABORTS,XMEAN6,VAR6,HIGH6,
     1XLOW6,SD6,CVPCT6)
      CALL STATS(REHOOK3,NTURNS,TTIME7,XMEAN7,VAR7,HIGH7,
     1XLOW7,SD7,CVPCT7)
      CALL STATS(INHAUL1,NTURNS,TTIME8,XMEAN8,VAR8,HIGH8,
     1XLOW8,SD8,CVPCT8)
      CALL STATS(UNHOOK3,NTURNS,TTIME9,XMEAN9,VAR9,HIGH9,
     1XLOW9,SD9,CVPCT9)
      CALL STATS(REFUEL3,NTURNS,TREFUEL,XMEAN10,VAR10,
     1HIGH10,XLOW10,SD10,CVPCT10)
C...
```

```
C...  WRITE OUT THE STATISTICS FOR EACH EVENT FOR EACH
C...  CYCLE.  THIS WILL FIRST WRITE OUT THE INDIVIDUAL MEANS
C...  AND THEN THE VARIANCE,MAXIMUM,MINIMUM,STANDARD DEVIATION,
C...  AND LAST THE COEFFICIENT OF VARIATION.
C...
      WRITE(5,300)XMEAN1,XMEAN2,XMEAN3,XMEAN4,XMEAN5,
     1XMEAN11,XMEAN6,XMEAN7,XMEAN8,XMEAN9,XMEAN10
      WRITE(5,11)VAR1,VAR2,VAR3,VAR4,VAR5,VAR11,VAR8,VAR9,
     1VAR10
      WRITE(5,12)HIGH1,HIGH2,HIGH3,HIGH4,HIGH5,HIGH11,
     1HIGH7,HIGH8,HIGH9,HIGH10
      WRITE(5,13)XLOW1,XLOW2,XLOW3,XLOW4,XLOW5,XLOW11,XLOW7,
     1XLOW8,XLOW9,XLOW10
      WRITE(5,14)SD1,SD2,SD3,SD4,SD5,SD11,SD8,SD9,SD10
      WRITE(5,15)CVPCT1,CVPCT2,CVPCT3,CVPCT4,CVPCT5,CVPCT11,
     1CVPCT8,CVPCT9,CVPCT10
  300 FORMAT(5X,*MEAN*,10X,F7.4,1X,F7.4,1X,F7.4,6X,
     1F7.4,6X,F3.0,2X,F7.0,2X,F7.4,1X,F7.4,3X,F7.4,9X,F7.4,8X,F7
     1.4)
   11 FORMAT(5X,*VARIANCE*,6X,F7.4,1X,F7.4,1X,F7.4,6X,
     1F7.4,6X,F3.0,2X,F7.0,20X,F7.4,9X,F7.4,8X,F7.4)
   12 FORMAT(5X,*HIGH*,10X,F7.4,1X,F7.4,1X,F7.4,6X,F7.4,6X,
     1F3.0,2X,F7.0,2X,F7.4,1X,F7.4,3X,F7.4,9X,F7.4,8X,F7.4)
   13 FORMAT(5X,*LOW*,11X,F7.4,1X,F7.4,1X,F7.4,6X,F7.4,
     16X,F3.0,2X,F7.0,2X,F7.4,1X,F7.4,3X,F7.4,9X,F7.4,8X,F7.4)
   14 FORMAT(5X,*STAN. DEV.*,4X,F7.4,1X,F7.4,1X,F7.4,6X,F7.4,
     16X,F3.0,2X,F7.0,20X,F7.4,9X,F7.4,8X,F7.4)
   15 FORMAT(5X,*C.V. %*,8X,F7.2,1X,F7.2,1X,F7.2,6X,F7.2,6X,
     1F3.0,2X,F7.0,20X,F7.2,9X,F7.2,8X,F7.2)
      GO TO 190
   90 TIME11=0
  190 CONTINUE
C...
C...  REINITIALIZE THE TIME AND OTHER VALUES FOR FURTHER
C...  EXECUTION.
C...
      NTURNS1=0
      NTURNS=0
      TTIME1=0
      TTIME2=0
      TTIME3=0
      TTIME4=0
      TTIME6=0
      TTIME7=0
      TTIME8=0
      TIME10=0
      TTIME9=0
      TTIME10=0
      TTIME11=0
      TNLOGS=0
      TXVOLUME=0
      NCYC=NCYC+1
C...
C...  THIS STATEMENT CHECKS TO INSURE THAT ONLY FOUR CYCLES
C...  ARE FLOWN PER DAY.
C...
      IF(NCYC.GE.4)GO TO 7000
C...
C...  THIS STATEMENT CHECKS TO INSURE THAT THE NUMBER OF
C...  TURNS YARDED ARE NOT MORE THAT THE REQUIRED NUMBER OF
C...  TURNS THAT CAN BE YARDED BEFORE IT REQUIRES A REFUELING
C...  EVENT.
C...
```

```
      IF(TURN.GE.XTURNS3)GO TO 6000
C...
C...
C...  THIS STATEMENT PASSES THE ARRAY XCELL- WHICH CONTAINS
C...  THE TURN BY TURN TIME  ARC USES  IT TO COMPUTE
C...  THE PREVIOUSLY MENTIONED STATISTICS.
C...
 7000 CALL STATS(XCELL,NADD,TTIME,XMEAN12,VAR12,XHIGH12,XLOW12,S
     1D12,CVFCT12)
      NADD=0.
      NCYC=0.
      TTIME=0.
      XMEAN3(NSYDIST)=XMEAN12
      STDEV3(NSYDIST)=SD12
      XHIGH22(NSYDIST)=XHIGH12
      XLOW22(NSYDIST)=XLOW12
C...
C...  THIS STATEMENT TERMINATES THE FIRST - NTAG - LOOP.
C...
 8888 CONTINUE
C...
C...  THIS WRITES OUT THE MEAN ,STANDARD DEVIATION ,MAXIMUM,
C...  AND MINIMUM VALUES FOR EACH OF SIXTY TREATMENTS.
C...
      WRITE(6,888)TAGLINE(NTAG),(XMEAN3(I),I=1,10),(STDEV3(I),I=
     11,10),(XHIGH22(I),I=1,10),(XLOW22(I),I=1,10)
  888 FORMAT(1X,F4.0,1X(4(10(5X,F7.2)/8X)))
  887 FORMAT(1X,/TAGLINE/,10(5X,F7.0))
C...
C...  THIS TERMINATES THE NSYDIST DO LOOP.
C...
 8889 CONTINUE
      WRITE(6,449)
  449 FORMAT(58X,/CHORDSLIP=10%/)
C...
C...  THE SUBROUTINES ARE LISTED BELOW:
C...
      STOP
      END
C...
C...
C...
      SUBROUTINE ABORT2(U,TIME6,ABORT,ABORT1)
C...
C...  ABORT2 ENTERS THE CONTINUOUS CUMULATIVE DENSITY
C...  FUNCTION FOR THE DURATION OF ABORT DELAYS WITH A
C...  UNIFORMLY DISTRIBUTED RANDOM VARIATE FROM "RANDOM"
C...  AND RETURNS A VALUE FOR THE DURATION OF AN ABORT
C...  DELAY.
C...
      DIMENSION ABORT (1), ABORT1(1)
      IF(U.GE.ABORT(1))GO TO 10
      TIME6=0.
      RETURN
   10 CONTINUE
      DO 130 I=2,18
      IF(U.LT.ABORT(I))GO TO 140
  130 CONTINUE
  140 J=I-1
      A=(ABORT1(I)-ABORT1(J))/(ABORT(I)-ABORT(J))
      TIME6=ABORT1(J)+(A*(U-ABORT(I)))
      RETURN
      END
```

```
C...
C...
C...
      SUBROUTINE REHOOK2(U,TIME7,REHOOK,REHOOK1)
C...
C...  REHOOK2 ENTERS THE CONTINUOUS CUMULATIVE DENSITY
C...  FUNCTION FOR THE DURATION OF REHOOK DELAYS WITH
C...  A UNIFORMLY DISTRIBUTED RANDOM VARIATE FROM
C...  "RANDOM" AND RETURNS A VALUE FOR THE DURATION OF
C...  THE REHOOK DELAY.
C...
      DIMENSION REHOOK(1),REHOOK1(1)
      IF(U.GE.REHOOK(1))GO TO 10
      TIME7=.4
      RETURN
   10 CONTINUE
      DO 130 I=2,8
      IF(U.LT.REHOOK(I))GO TO 110
  130 CONTINUE
  110 J=I-1
      A=(REHOOK1(I)-REHOOK1(J))/(REHOOK(I)-REHOOK(J))
      TIME7=REHOOK1(J)+(A*(U-REHOOK(J)))
      RETURN
      END
C...
C...
C...
      SUBROUTINE UNHOOK2(U,TIME9,UNHOOK,UNHOOK1)
C...
C...  UNHOOK2 ENTERS THE CONTINUOUS CUMULATIVE DENSITY
C...  FUNCTION FOR THE DURATION OF UNHOOK TIMES WITH A
C...  UNIFORMLY DISTRIBUTED RANDOM VARIATE FROM "RANDOM"
C...  AND RETURNS A VALUE FOR THE DURATION OF THAT
C...  UNHOOKING EVENT.
C...
      DIMENSION UNHOOK(1),UNHOOK1(1)
      IF(U.GE.UNHOOK(1))GO TO 10
      TIME9=0.
      RETURN
   10 CONTINUE
      DO 100 I=2,10
      IF(U.LT.UNHOOK(I))GO TO 50
  100 CONTINUE
   50 J=I-1
      A=(UNHOOK1(I)-UNHOOK1(J))/(UNHOOK(I)-UNHOOK(J))
      TIME9=UNHOOK1(J)+(A*(U-UNHOOK(J)))
      RETURN
      END
C...
C...
C...
      SUBROUTINE REFUEL2(U,TIME10,REFUEL,REFUEL1)
C...
C...  REFUEL2 ENTERS THE CONTINUOUS CUMULATIVE
C...  DENSITY FUNCTION FOR THE DURATION OF REFUELING
C...  EVENTS WITH A UNIFORMLY DISTRIBUTED RANDOM VARIATE
C...  FROM "RANDOM" AND RETURNS A VALUE FOR THE DURATION
C...  OF REFUELING EVENT.
C...
      DIMENSION REFUEL(1),REFUEL1(1)
      IF(U.GE.REFUEL(1))GO TO 10
      TIME10=3.4
      RETURN
```

```
   10  CONTINUE
       DO 140 I=2,16
       IF(U.LT.REFUEL(I))GO TO 20
  140  CONTINUE
   20  J=I-1
       A=(REFUEL1(I)-REFUEL1(J))/(REFUEL(I)-REFUEL(J))
       TIME10=REFUEL1(J)+(A*(U-REFUEL(J)))
       RETURN
       END
C...
C...
C...
       SUBROUTINE VOLUME2(U,NLOGS,VOLUME,VOLUME1,XVOLUME)
C...
C...   VOLUME2 ENTERS THE CONTINUOUS CUMULATIVE DENSITY
C...   FUNCTION FOR THE VOLUMES OBSERVED WITH A
C...   UNIFORMLY DISTRIBUTED RANDOM VARIATE FROM "RANDOM"
C...   AND RETURNS A VALUE FOR THE VOLUME OF EACH TURN
C...   BASED ON THE CDF VALUE RETURNED FROM "LOGS2".
C...
       DIMENSION VOLUME(6,1),VOLUME1(6,1)
       IF(U.GE.VOLUME(NLOGS,1))GO TO 10
       XVOLUME=VOLUME1(NLOGS,1)
       RETURN
   10  CONTINUE
       DO 100 I=2,102
       IF(U.LT.VOLUME(NLOGS,I))GO TO 110
  100  CONTINUE
  110  J=I-1
       A=(VOLUME1(NLOGS,I)-VOLUME1(NLOGS,J))/(VOLUME(NLOGS,I)-
      1VOLUME(NLOGS,J))
       XVOLUME=VOLUME1(NLOGS,J)+(A*(U-VOLUME(NLOGS,J)))
       RETURN
       END
C...
C...
C...
       SUBROUTINE OUTHAUL(TAGLINE,SYDIST,TIME2)
C...
C...   OUTHAUL COMPUTES AN OUTHAUL TIME FROM A REGRESSION
C...   EQUATION UTILIZING TAGLINE LENGTH AND SLOPE YARDING
C...   DISTANCE.
C...
       TIME2=.52873-.00059546*TAGLINE+.00022581*SYDIST
       RETURN
       END
C...
C...
C...
       SUBROUTINE INHAUL(NLOGS,SYDIST,CHORDSLP,TAGLINE,XVOLUME,TI
      1ME8)
C...
C...   INHAUL COMPUTES AN INHAUL TIME FROM A REGRESSION
C...   EQUATION UTILIZING SLOPE YARDING DISTANCE
C...   ,CHORDSLOPE,NUMBER OF LOGS PER TURN,TAGLINE
C...   LENGTH,AND VOLUME PER LOG.
C...
       TIME8=.74904+.00015991*SYDIST-.0037517*CHORDSLP+
      1.019075*NLOGS-.0014931*TAGLINE+.00072418*(XVOLUME
      1/FLOAT(NLOGS))
       RETURN
       END
C...
```

```
C...
C...
      SUBROUTINE RANDOM(IR,IA,IC,U,I)
C...
C...  RANDOM COMPUTES A PSEUDO RANDOM NUMBER EMPLOYING
C...  A MIXED CONGRUENTIAL RANDOM NUMBER GENERATOR TO
C...  BE USED IN THE RESPECTIVE SUBROUTINE.
C...
      DIMENSION IR(1),IA(1),IC(1)
      IR(I)=AND(AND(IA(I)*IR(I),8388607)+IC(I),8388607)
      U=IR(I)/8388607.
      RETURN
      END
C...
C...
C...
      SUBROUTINE CHOKO2(U,TIME1,CHCKO,CHCKO1)
C...
C...  CHOKO2 ENTERS THE CONTINUOUS CUMULATIVE DENSITY
C...  FUNCTION FOR THE DURATION OF CHOKER HOOKUP DELAYS
C...  WITH A UNIFORMLY DISTRIBUTED RANDOM VARIATE FROM
C...  "RANDOM" AND RETURNS A VALUE FOR THE DURATION OF
C...  EACH CHOKER HOOKUP DELAY.
C...
      DIMENSION CHOKO(1),CHOKO1(1)
      IF(U.GE.CHOKO(1))GO TO 10
      TIME1=0.
      RETURN
   10 CONTINUE
      DO 100 I=2,9
      IF(U.LT.CHCKO(I))GO TO 110
  100 CONTINUE
  110 J=I-1
      A=(CHCKO1(I)-CHCKO1(J))/(CHOKO(I)-CHOKO(J))
      TIME1=CHOKO1(J)+(A*(U-CHOKO(J)))
      RETURN
      END
C...
C...
C...
      SUBROUTINE HOOK2(U,TIME4,HOOK,HOOK1)
C...
C...  HOOK2 ENTERS A CONTINUOUS CUMULATIVE DENSITY FUNCTION
C...  FOR THE DURATION OF HOOK TIMES WITH A UNIFORMLY
C...  DISTRIBUTED RANDOM VARIATE FROM "RANDOM" AND RETURNS
C...  A VALUE FOR THE DURATION OF THAT HOOKING EVENT.
C...
      DIMENSION HOOK(1),HOOK1(1)
      IF(U.GE.HOOK(1))GO TO 10
      TIME4=.1
      RETURN
   10 CONTINUE
      DO 130 I=2,26
      IF(U.LT.HOOK(I))GO TO 140
  130 CONTINUE
  140 J=I-1
      A=(HOOK1(I)-HOOK1(J))/(HOOK(I)-HOOK(J))
      TIME4=HOOK1(J)+(A*(U-HOOK(J)))
      RETURN
      END
C...
C...
C...
```

```
      SUBROUTINE LOGS2(U,NLOGS,LOGS,LOGS1)
C...
C...  LOGS2 RANDOMLY SELECTS A GIVEN TURN SIZE
C...  (1 THROUGH 6 LOGS/TURN) FROM A DISCRETE CUMULATIVE
C...  DENSITY FUNCTION.
C...
      REAL LOGS, LOGS1
      DIMENSION LOGS(1),LOGS1(1)
      DO 150 I=1,6
      IF(U.LE.LOGS(I))GO TO 160
 150  CONTINUE
 160  NLOGS=LOGS1(I)
      RETURN
      END
C...
C...
C...
      SUBROUTINE CHOKI2(U,TIME3,CHOKI,CHOKI1)
C...
C...  CHOKI2 ENTERS THE CONTINUOUS CUMULATIVE DENSITY
C...  FUNCTION FOR THE DURATION OF CHOKER DELIVERY TIMES
C...  WITH A UNIFORMLY DISTRIBUTED RANDOM VARIATE FROM
C...  "RANDOM" AND RETURNS A VALUE FOR THE DURATION OF
C...  THAT CHOKER DELIVERY DELAY.
C...
      DIMENSION CHOKI(1),CHOKI1(1)
      IF(U.GE.CHOKI(1))GO TO 10
      TIME3=0.
      RETURN
  10  CONTINUE
      DO 110 I=2,11
      IF(U.LT.CHOKI(I))GO TO 120
 110  CONTINUE
 120  J=I-1
      A=(CHOKI1(I)-CHOKI1(J))/(CHOKI(I)-CHOKI(J))
      TIME3=CHOKI1(J)+(A*(U-CHOKI(J)))
      RETURN
      END
C...
C...
C...
      SUBROUTINE STATS(ARRAY,N,TOTAL,XMEAN,VAR,HIGH,XLOW,SD,
     1CVPCT)
C...
C...  STATS COMPUTES THE MEAN, VARIANCE,STANDARD DEVIATION,
C...  COEFFICIENT OF VARIATION, MAXIMUM AND MINIMUM VALUES FOR
C...  AN ARRAY.
C...
      DIMENSION ARRAY(1)
      XVAR=0
      HIGH=-.6E308
      XLOW=.6E308
      XMEAN=TOTAL/N
      DO 10 I=1,N
      IF(ARRAY(I).GE.HIGH)HIGH=ARRAY(I)
      IF(ARRAY(I).LE.XLOW)XLOW=ARRAY(I)
      XVAR=XVAR+(ARRAY(I)-XMEAN)*(ARRAY(I)-XMEAN)
  10  CONTINUE
      VAR=XVAR/FLOAT(N-1)
      SD=SQRT(VAR)
      IF(XMEAN.LE.0.)GO TO 20
      CVPCT=SD/XMEAN*100
  20  RETURN
```

```
      END
C...
C...
C...
      SUBROUTINE XTURNS1(U,CHOKI4,CHOKI5,NXTURNS)
C...
C...  XTURNS1 ENTERS A CONTINUOUS CUMULATIVE FUNCTION FOR
C...  THE NUMBER OF TURNS THAT MUST BE YARDED BEFORE A
C...  CHOKER HOOKUP EVENT OCCURS.  A UNIFORMLY DISTRIBUTED
C...  RANDOM VARIATE FROM "RANDOM" IS USED TO DETERMINE THE
C...  VALUE OF THE CHOKER HOOKUP DELAY.
C...
      DIMENSION CHOKI4(1),CHOKI5(1)
       DO 112 I=1,20
      IF(U.LE.CHOKI4(I))GO TO 200
  112 CONTINUE
  200 NXTURNS=CHOKI5(I)
      RETURN
      END
C...
C...
C...
      SUBROUTINE XTURNS2(U,REFUEL4,REFUEL5,XTURNS3)
C...
C...  XTURNS2 ENTERS THE CONTINUOUS CUMULATIVE DENSITY
C...  FUNCTION FOR THE FREQUENCY OF REFUELING EVENTS WITH
C...  A UNIFORMLY DISTRIBUTED RANDOM VARIATE FROM
C...  "RANDOM" AND RETURNS THE VALUE THAT WILL DETERMINE
C...  THE FREQUENCY OF REFUELING EVENTS.
C...
      DIMENSION REFUEL4(1),REFUEL5(1)
      DO 150 I=1,16
      IF(U.LE.REFUEL4(I))GO TO 180
  150 CONTINUE
  180 XTURNS3=REFUEL5(I)
      RETURN
      END
C...
C...
```