SIMULATION STUDY OF INITIAL ATTACK FIRE OPERATIONS

IN THE WHITECOURT FOREST, ALBERTA

BY

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ABSTRACT

Fire, weather, and dispatch data from the Whitecourt Forest, 1961-1969, provided the basis for developing an intital attack simulation model. A study team from the Alberta Forest Service, the Northern Forest Research Centre, and the University of Alberta collectively designed the model, extracted data, and analyzed results during workshop sessions.

Six suppression methods used for initial attack in Alberta were run against 485 actual fires, and success and associated costs were tabulated. Thirteen four-man handcrews, the normal complement in the Whitecourt Forest, were 64% successful, a 204B helitanker was 59% successful, an amphibious PBY-Canso was 52% successful, a B-26 was 46% successful, a land-based PBY-Canso was 30% successful, and a 206B helitanker was 18% successful. Expenditures are summarized for each method.

RESUME

On a élaboré un modèle de simulation de lutte initiale contre le feu, fondé sur des données relatives aux incendies, aux conditions atmosphériques et provenant de dépêches de la forêt Whitecourt pour les années 1961 à 1969. Un groupe d'étude conjointement formé par l'Alberta Forest Service, le Centre de recherches forestières du Nord et l'Université de l'Alberta a conçu le modèle, extrait des données et analysé les résultats au cours de session de travail.

On a utilisé six méthods de lutte initiale en Alberta contre 485 incendies réels et les succès obtenus, de même que les coûts y relatifs sont présentés sous forme de tableaux. Treize équipes de quatre hommes chacune (utilisant des méthodes manuelles), soit l'effectif complémentaire normal pour la forêt de Whitecourt, ont obtenu un succès de 64%; un hélicoptère 204B à réservoirs a obtenu 59% de succès; un appareil amphibie PBY-Canso a réussi dans une proportion de 52%; un B-26 obtenu 46% de succès; un avion ordinaire

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PBY-Canso en a obtenu 30% et enfin un hélicoptère 206B à réservoirs a réussi dans une proportion de 18%. L'article résume les dépenses inhérentes à chacune des méthodes employées.

CONTENTS

INTRODUCTION

Efficient and vigorous initial attack operations, which minimize damage and suppression expenditures, are the aim of all fire control organizations. Planning for improved initial attack requires current information relating complex suppression methods to economic guidelines.

A co-operative study was designed and implemented by the Northern Forest Research Centre (NFRC) and the Alberta Forest Service (AFS) to provide basic information for future initial attack strategy. A study team was organized to represent AFS headquarters and field personnel, NFRC, and computer expertise from the University of Alberta; and their objective was to utilize computer technology and simulation modelling to systematically assess the performance and economics of selected suppression methods. The team collectively designed and developed a simulation model and analyzed computer runs during workshop sessions. Statistics from a large population of fires in the Whitecourt Forest were used as inputs for the model to test the performance of handcrews, airtankers, and helitankers.

The study developed in well-defined steps to ensure the full involvement of research and operational personnel. Initial workshop sessions dealt with the philosophy and written policy of the initial attack operation in Alberta, the role of research in traditional operational problem areas, and finally, the objectives of this study. Many early workshop sessions were informal and unstructured to allow open discussion among field, headquarters, and research representatives. These initial forums established a solid line of communication among the agencies and disciplines involved, and the dividends were reaped in later technical sessions.

Simulation modelling is often used to duplicate a "real world" system which is either too complex or unwieldy to feasibly study by more traditional means. The performance of initial attack forces is one such case. Fire control staff cannot afford to experiment with alternative attack strategies while fires potentially threaten lives and commercial resources.

The simulation technique provides a means of testing and refining resource performance without associated risk; however, there are acknowledged constraints.

This model does not attempt to optimize the allocation of resources in individual or multiple fire situations. It will act as a decision-making aid for operational planning functions at the headquarters level. The principal output is information on the fire-line-building capabilities of six initial attack methods for five regional fuel types over a range of fire spread rates. Fuel and fire parameters are fixed, while fire-line productivity rates, dispatch times, and operational costs vary according to the attack system.

METHODS

DATA SOURCE

The Study Area

The Whitecourt Forest is situated in Central Alberta at the southern extreme of the Boreal Forest Region (Rowe 1972). The district is approximately 160 x 240 km and averages 87 fires per year (Miyagawa 1974). It was selected for this study on the basis of its representativeness of other forests, its suitability to the common initial attack methods, and the availability of data.

Almost the entire eastern boundary fronts the agricultural zone and is accessible by road, while a dense network of gas- and oil-well roads exists in the interior. Water sources for amphibious airtankers and helitankers are adequate and the forest is serviced by major airtanker bases at Edson, Whitecourt, and Fox Creek. Figure 1 identifies the handcrew, airtanker, and helitanker bases used in the simulation model.

Weather

Records from 14 weather stations within and adjacent to the Whitecourt Forest Boundary (Fig. 1) provided weather readings for May to September, 1961-69. Years 1961-65 required manual extraction from station records while years 1966-69 were available on magnetic tape. The 1200-h

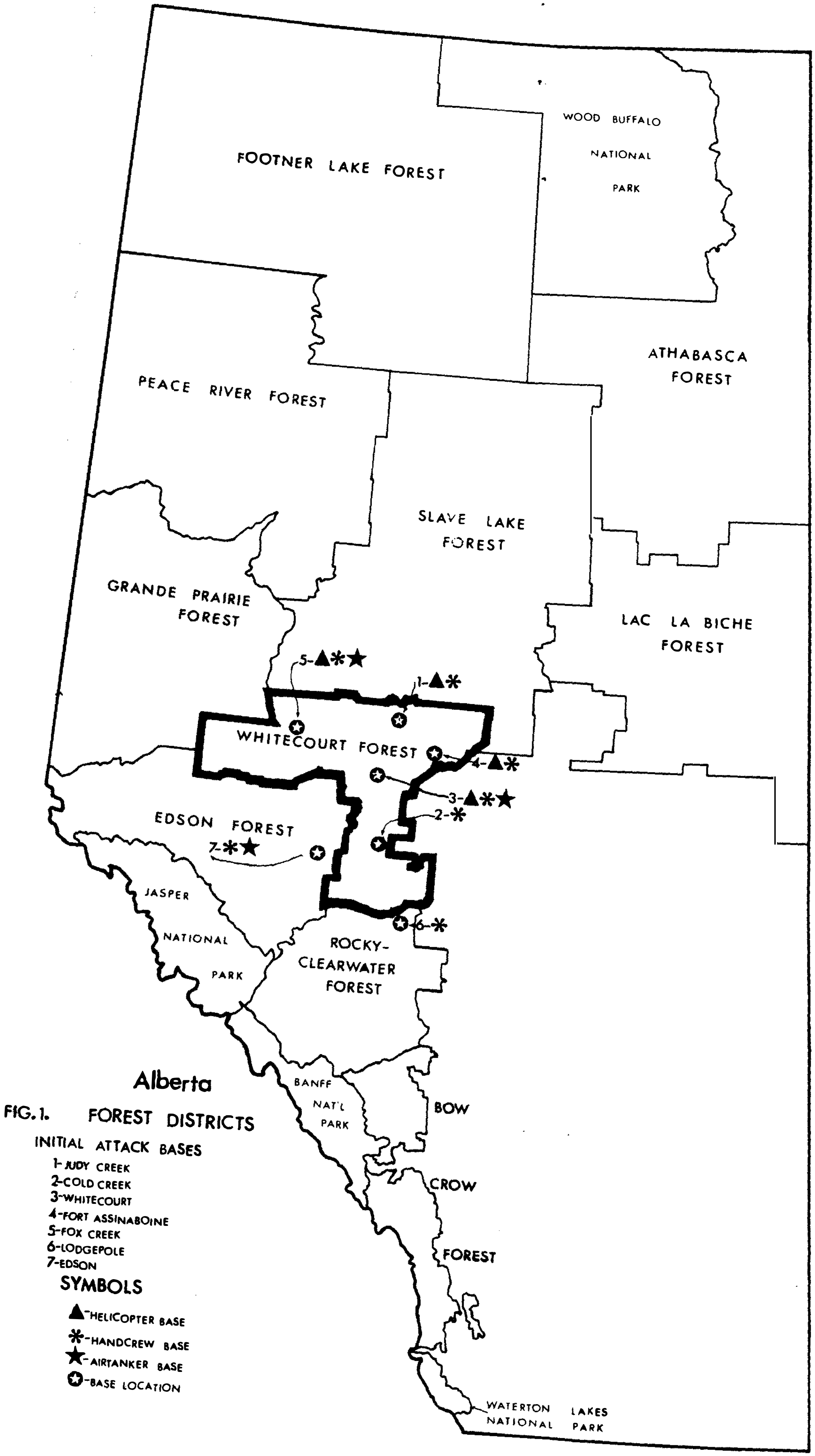


FIG. 1. FOREST DISTRICTS

observations of temperature, relative humidity, wind velocity, and precipitation were used to calculate the Fire Weather Index (FWI) (Anon. 1970; Van Wagner 1974) for each day of the 10-yr period. Days with one or more fires were then referenced back to the weather tape and the Initial Spread Index (ISI) (a component of the Fire Weather Index Tables derived from wind and fine fuel moisture) as a means of estimating fire spread rates. (A more complete discussion of fire spread is given under Fire Growth Model.)

Fires

A total of 775 fires was recorded through the Whitecourt office during 1961-69, with 599 of these occurring between May and September. The 114 fires located in the agricultural zone were excluded, leaving 485 as the basis of this study. Location, start time, detection time, slope, aspect, and fuel type were documented for each of the 485 fires.

Fire occurrence is illustrated in Fig. 2 for the 10-yr period in the Whitecourt Forest. Fires were well distributed geographically, providing a good range of travel distances from handcrew, airtanker, and helitanker bases. The lack of fires in the southern extreme of the forest was a result of an interim boundary change.

RESOURCES

Initial attack resources common to the central and northern forest districts in Alberta include handcrews, airtankers, and helitankers. Handcrews are normally available in all forests throughout the fire season and contract aircraft are rotated according to fire hazard. In this study 13 four-man crews were assumed to be the typical manning level in the Whitecourt Forest. It is normal procedure to combine aircraft and men during initial attack; however, the first model run was designed to assess performance of available manpower in the forest relative to a basic aircraft unit. The model is currently being expanded to consider operational combinations of men and aircraft.

The initial attack period was defined as the interval between first suppression contact and 10:00 a.m. the following day for all

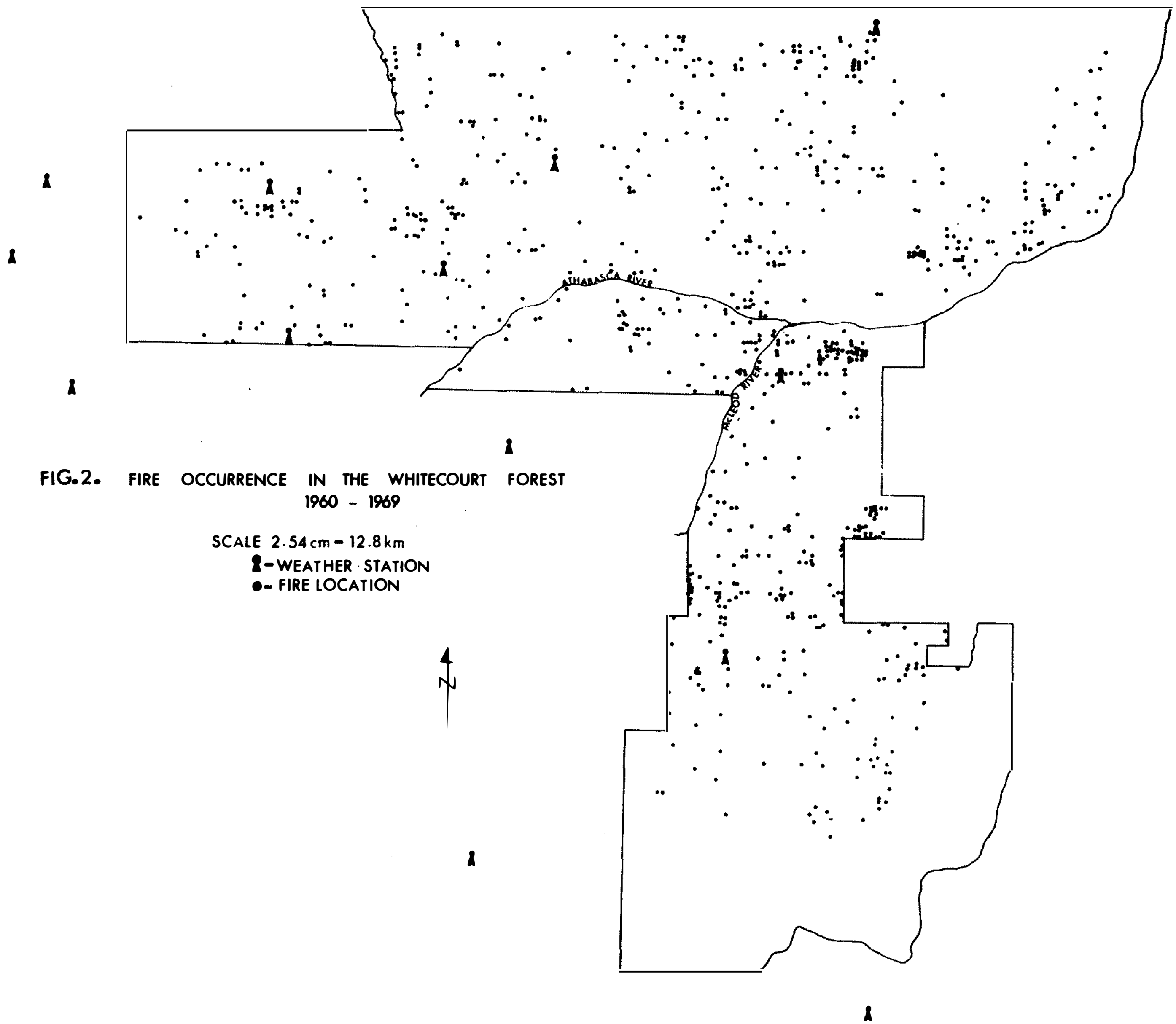


FIG. 2. FIRE OCCURRENCE IN THE WHITECOURT FOREST
1960 - 1969

SCALE 2.54 cm = 12.8 km
– WEATHER STATION
● – FIRE LOCATION

suppression methods. A method was successful if fire line built exceeded fire perimeter during the initial attack period.

The individual methods are discussed in detail below:

Handcrews

Seven dispatch centers were used as initial attack crew bases in the Whitecourt Forest. Field staff involved in the study calculated ground travel times and distances to each fire for the closest and second closest dispatch center, using existing roadways and trails. The seven dispatch centers are:

	No. of Crews
1. Judy Creek	5
2. Cold Creek	3
3. Whitecourt	1
4. Ft. Assiniboine	1
5. Fox Creek	1
6. Lodgepole	1
7. Edson	1

Dispatch rules listed below were developed by experienced field staff familiar with the Whitecourt district:

(1) The five standby centers were to be used as realistically as possible, i.e., crew nearest to fire dispatched automatically unless it had been committed to an earlier fire for more than 8 h.

(2) Crews would work continuously until 10:00 a.m. the next day.

(3) If all crews were committed to fires, new starts were not considered lost until 10:00 a.m. the next day, since returning crews would be reassigned if they had worked less than 8 h.

Handcrew production rates used in the model were derived from experienced field personnel estimates and recent data from Study NOR-128, on file at NFRC. These rates reflect optimum production conditions and consist of the scratch line and hot spotting technique and the trenching technique, which are commonly combined during the initial attack period. Average production for the first hour is listed in Table 1. After the first hour a reduction of 10% per hour was applied up to the fifteenth hour, when production was assumed to be a constant 23% of the first hour.

Helitankers

Five crew centers were designated as helicopter bases for the 204B and 206 Jet Ranger with 1067- and 409-ℓ buckets respectively. Water sources were identified for all fires in the 10-yr period, and once the helicopter was dispatched it worked directly from the water source to the fire, returning only for fuel and night overlays at the nearest base. Operational data for the two helicopters are given in Table 2. Airdrop patterns from Grigel et al. (1974) were modified for the five fuel types using an application level of 1.80 mm of water (equivalent to 1.00 mm of long-term retardant) as an effective fire-line criterion (Personal communication, R. Newstead and R. Lieskovsky) (Table 1).

Helicopter bases are:

- Whitecourt
- Fox Creek
- Cold Creek
- Judy Creek
- Ft. Assiniboine

Airtankers

The Whitecourt, Edson, and Fox Creek airstrips were used as dispatch bases for the airtankers loading long-term retardant. The PBY Canso worked as a land-based tanker from the three bases and, in a separate run, as an amphibious tanker from nine lakes. In the land-based operations tanker loads were adjusted below actual capacity based on field experience. Operational data for the airtankers are given in Table 2.

Cruise speed, endurance, and dispatch and refuel times are from AFS field personnel and Simard and Forster (1972). Flying rates and retardant prices are 1974 figures and accuracy percentages are from the NFRC. Drop patterns are modified from Grigel (1972) and unpublished data at the NFRC.

Table 1. Fire-line production rates by fuel type

Suppression method		Fuel type				
		Spruce	Pine	Hardwood[1]	Muskeg	Slash
Handcrew (4 men)	metres/minute	2.0	2.5	2.8	0.6	0.6
B-26[2]	metres/drop	22.3	20.0	33.5	26.6	49.7
PBY Canso[2] -land based	metres/drop	18.0	16.0	26.9	20.8	33.3
PBY Canso[3] -amphibious	metres/drop	20.0	17.8	30.0	23.1	37.1
206B[3]	metres/drop	1.0	1.0	1.2	1.2	3.0
204B[3]	metres/drop	7.6	6.4	8.9	8.1	20.3

[1] Spring or fall condition assumed

[2] 1.0 mm application level--long-term retardant

[3] 1.8 mm application level--water

Table 2. Operational data for fixed and rotary wing aircraft based on estimated use in the Whitecourt Forest

		Aircraft				
		B-26	PBY Canso -land based	PBY Canso -amphibious	204B	206B
Cruise speed	km/h	174	90	90	65	65
Endurance allowed in model	h	3	10	10	2	2
Retardant/water capacity	ℓ	4546	3637	3637	1068	409
Actual load allowed in model	ℓ	3637	3182	3637	1068	409
Accuracy (%)		75	80	80	100	100
Dispatch time (min)		30	30	30	15	15
Flying rate		$200/h + $750/day	$180/h + $750/day	$180/h + $750/day	$640/h + $920/day	$300/h + $900/day
Retardant cost on board airtanker	$/ℓ	0.165	0.165	-	-	-
Refuel time (min)		8	8	8	5	5

FIRE GROWTH MODEL

No mathematical model exists that is capable of duplicating the exact growth of wildland fires. Wildfires do, however, follow general geometric shapes, one of the most common being an elipse. An eliptical fire growth model (Van Wagner 1968a) was used in this study to provide the dynamics of fire growth from discovery time to control time or 10:00 a.m. the day following detection. Perimeter and area could be readily calculated from headfire and backfire spread rates for any given day of the fire season. Available fire behavior data (Van Wagner 1968b; Telitsyn 1969; Quintilio 1972; Lawson 1973; Kiil 1975) and the collective judgment of the study team were used to develop headfire spread rates and proportional flank and rear spread rates. The headfire spread tables were derived for five fuel types (Appendix I) as a function of the ISI.

The basic spread figures were subsequently adjusted for each fire to account for slope, aspect, and the diurnal change of fine fuel moisture (Appendix II). Headfire spread rates (Vi) are read from Appendix I using appropriate fuel type, wind, and fine fuel moisture, while backfire (Ui) and flankfire rates are read from fuel type and fine fuel moisture along the 0.0 wind row.

Fire growth for a time increment is illustrated in Fig. 3 and the formulae for area (A) and perimeter (P) are given below:

$$A = \pi \frac{(X + Y)}{2} Z \quad \ldots\ldots (1)$$

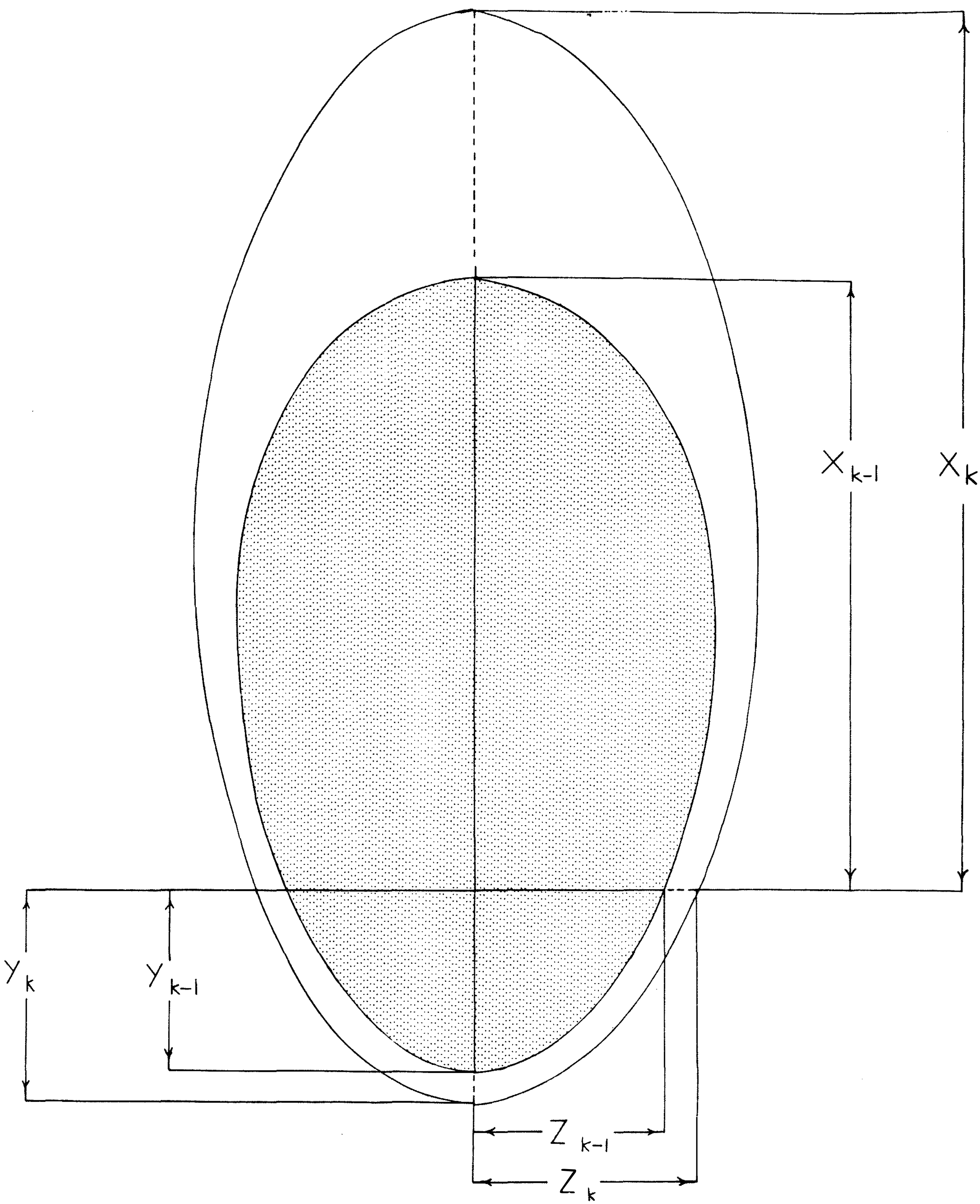
$$P = \pi \left(\frac{X + Y}{2} + Z\right) \left(1 + \frac{M^2}{4}\right) \quad \ldots\ldots (2)$$

$$\text{where } M = \frac{\left(\frac{X + Y}{2} - Z\right)}{\left(\frac{X + Y}{2} + Z\right)} \quad \ldots\ldots (3)$$

X is distance that the headfire has advanced from the starting point

Y is distance that the backfire has advanced from the starting point

FIG. 3. ELLIPTICAL FIRE GROWTH FOR TIME PERIOD Δt



Z is distance that the flankfire has advanced from the starting point.

Fire growth prior to contact by initial attack forces was calculated hourly. Growth after contact was calculated for Δt increments according to the timing of suppression operations using the following formulae specific to the kth time increment:

$$X_k = X_{k-1} + Vi\ \Delta t \qquad (4)$$

$$Y_k = X_{k-1} + Ui\ \Delta t \qquad (5)$$

$$Z_k = Y_k \text{ if } X_k < 4\ Y_k \qquad (6)$$

$$Z_k = .25\ X_k \text{ if } X_k > 4\ Y_k \qquad (7)$$

The time increment Δt is .1 h for handcrews and the length of one cycle (total time for one drop) for aircraft.

Area and perimeter as influenced by the suppression operation were calculated using the following formulae:

$$C_k = C_{k-1} + \left[1 - \left(\frac{F_{k-1}}{C_{k-1}} \right) \right] (P_k - P_{k-1}) \qquad (8)$$

$$S_k = S_{k-1} + \left[1 - \left(\frac{F_{k-1}}{C_{k-1}} \right) \right] (A_k - A_{k-1}) \qquad (9)$$

$$F_k = F_{k-1} + L_k \qquad (10)$$

Where P_k = Theoretical perimeter of the fire at the end of the kth time increment if there were no initial attack

A_k = Theoretical area of the fire at the end of the kth time increment if there were no initial attack

C_k = Actual perimeter of the fire (including fire line) at the end of the kth time increment

S_k = Actual area of the fire at the end of the kth time increment

L_k = Fire line constructed during time increment k

F_k = Total fire line constructed at the end of the increment k.

It was recognized that when the fire line constructed by initial attack forces was much less than the growth in perimeter of the fire there would be substantial losses in the amount of effective fire line. In these cases fire advancement was assumed to follow the classical fire growth model even though fire could well burn around the ends of line previously constructed.

One further adjustment was made to the fire growth model as a result of initial attack. When the fire line exceeded 40% of the total perimeter of the fire it was assumed that the headfire spread was stopped (i.e., Vi = 0). Subsequent growth was then a function of flank and rear spread rates. Flank spread was, at that time, equated to rear spread.

SIMULATION MODEL

Simulation exercises can be both time-consuming and expensive and there are inherently many opportunities to deviate from the "real world". The task of the modeller is therefore to strike a balance between the complex realities of a problem and a solution to that problem, and results must be interpreted in light of the philosophy and input of the particular model. A general approach to developing a simulation model is illustrated in Fig. 4 by Dent and Anderson (1971).

The concept of workshop modelling is described by Holling et al. (1971), and this approach was adopted as the best method of developing an initial attack simulation model that would satisfy both research and field personnel. A study team was therefore assigned at the inception of the proposal. Two AFS Fire Control Officers provided firsthand knowledge of the Whitecourt Forest operation, two AFS operations and planning personnel added the perspective and foresight of the headquarters level, and a research team assembled the data and built the model. Detailed work was contributed independently by team members but the problems of simulating a large complex system were dealt with in workshop sessions. The central objective throughout the exercise was to simplify enough to expedite the programming, yet maintain relevance in critical areas.

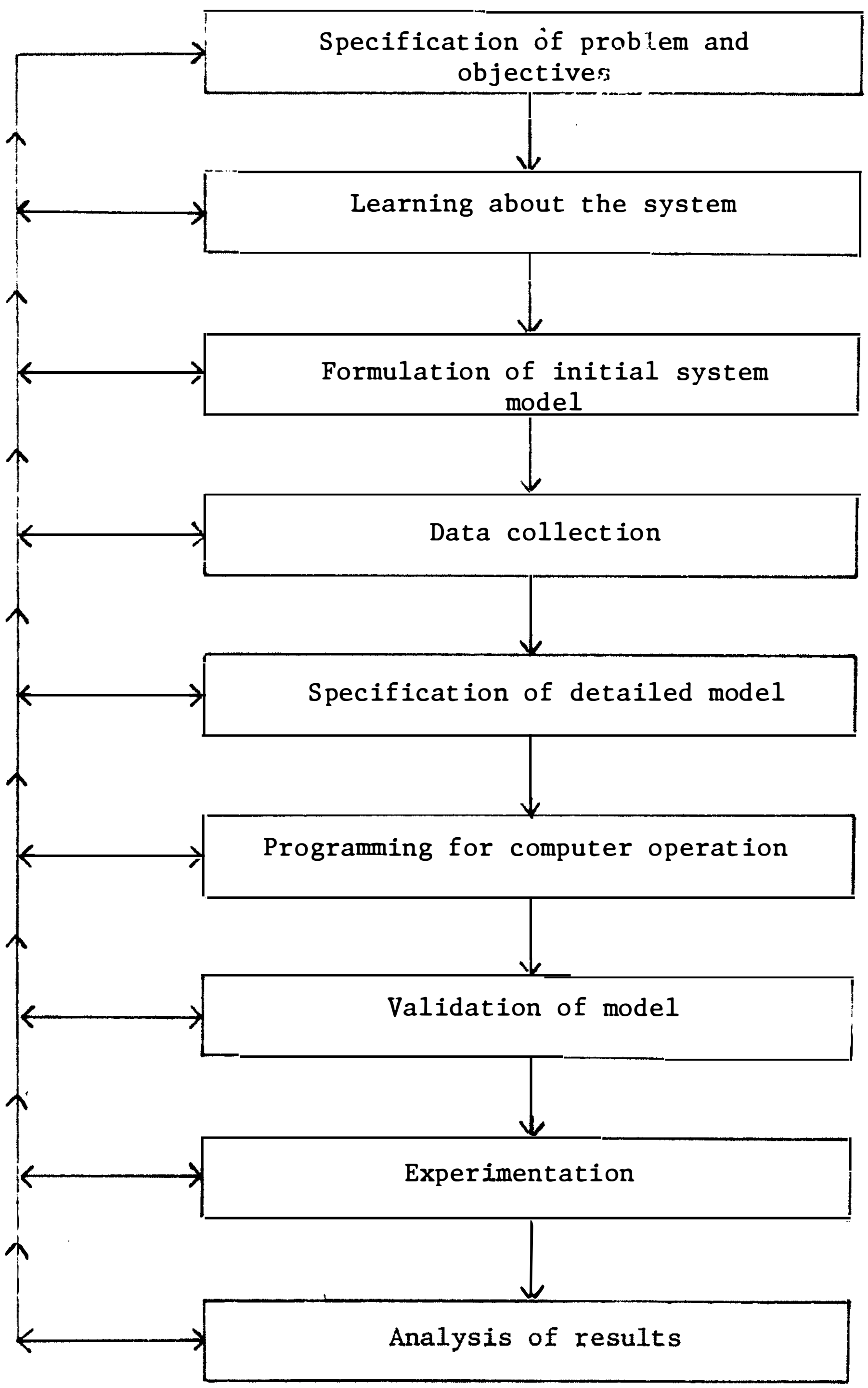


Figure 4. General simulation methodology.

The initial attack model for this study was programmed under contract by the second author and run at the University of Alberta. The model consists of two computer programs which were written in modular styles i.e., the major steps in the procedure were defined as program modules or subroutines and these were linked together using an executive program. Flow charts of the executive programs of the model are shown in Fig. 5. The present model uses historical data but provision has been made in the computer programs for future use of probability functions to generate weather and fires. A description of the model variables is given in Appendix III.

The first computer program, used only once in the project, developed a weather tape which describes fire weather data for 14 weather locations. The subroutines in this program perform the following steps:

a) Reading into the computer the description of the weather stations and tables for FWI calculations

b) Daily calculations for the following:

  i) Reading into the computer the weather observations for one day for each weather station

  ii) Calculating the FWI parameters for each of the 14 stations

  iii) Writing a record of all weather data for the 14 stations for that day on computer tape for use by the next program.

The second program was used to grow each fire and to simulate the operation of the initial attack forces, and the steps in the program were

a) Reading into the computer the description of the tactical resources and fire control capability

b) Daily calculations for the following:

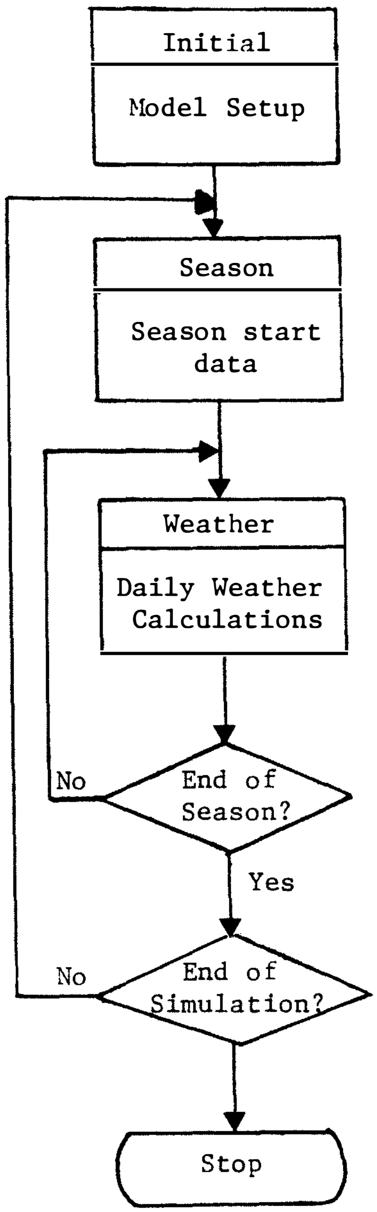
  i) Reading into the computer the fire weather for that day (from program I)

  ii) Reading into the computer a description of the fires for the day (up to 30)

  iii) Calculation of fire growth until detection for each fire

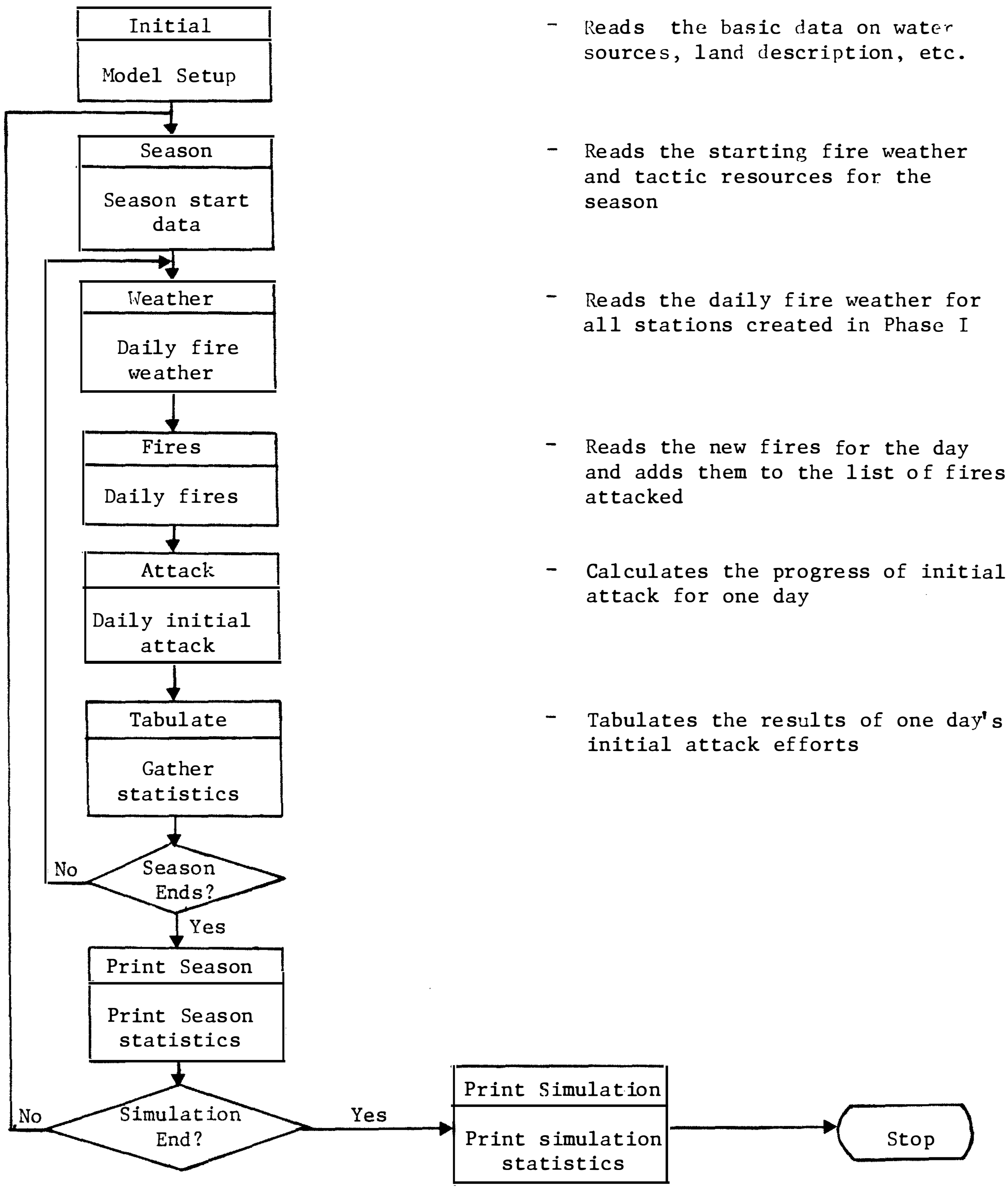
Fig. 5 Flowchart of Executive Program for Initial Attack Simulator.

Phase I. Generate Daily Fire Weather Tape.



- Reads the information for calculation of fire weather from cards
- Reads the beginning fire weather for each year
- Reads one day's weather data for all weather stations and calculates the fire weather data for each station. Then the fire weather for all stations for the day is written on a tape for Phase II.

Phase II. Simulation of Initial Attack



iv) Calculation of the impact of fire control efforts through the day on each fire

v) Accumulation of statistics for fires that have reached a terminal point during the day (i.e. controlled or the end of the initial attack period)

c) Seasonal calculations for:

i) Printing tables summarizing the results of initial attack efforts for the season

ii) Accumulating statistics on the initial attack efforts for the total simulation run

d) Printing tables summarizing the results of initial attack systems

The variety of initial attack tactics required that several subroutines be altered for analysis of each tactic.

The model was programmed using FORTRAN. The sequence of the model was conceived by regarding initial attack as a waiting line process. Discovery of fire placed it into the waiting line where it increased in size according to the fire growth model and the fuel and weather parameters. An initial attack method was dispatched to the fire and began fire-line construction. Fire growth and accumulated fire line built were calculated iteratively (i.e. in time-unit increments which varied depending on tactic) until the fire line built equaled or exceeded fire perimeter or until 10:00 a.m. on the day following detection. The fire than left the system as either controlled or uncontrolled with the statistics for the fire merged with the statistics describing the performance of the initial attack tactic. In multiple-fire situations, some fires might be lost (not attacked) because of a lack of resources. These fires were tabulated as not attacked and the ratio of fires attacked to total fires is one measure of the performance of each tactic. For all systems, performance statistics are summarized by season and for the complete 10-yr period.

RESULTS

A total of 485 fires was available for attack by the six suppression methods. Fires actually attacked ranged from 317 by the 206B helitanker to 447 by the 13 handcrews. Handcrews attacked 447 fires and successfully controlled 287 (64%). The 204B helitanker attacked 362 fires and controlled 213 (59%), which was the highest performance figure for aircraft. The 206B helitanker attacked 317 fires but controlled only 56 (18%), which was the worst performance figure for aircraft. The PBY-Canso loading water from lakes was 52% successful; the B-26 and PBY Canso, loading long-term retardant from airstrip bases, were 46% and 30% successful, respectively.

Table 3 summarizes performance and associated expenditures for the six suppression methods. Total costs include a fixed sum for contracting resources plus a variable cost calculated for each fire. The land-based B-26 and PBY-Canso dropping long-term retardant had the highest total costs, since the variable cost of long-term retardant contributes significantly to the total. The lowest total costs were those of the amphibious PBY-Canso.

Figures 6 to 11 illustrate the performance of each suppression method by fuel type and ISI. Fire incidence is normally distributed around the moderate values of ISI, with decreasing fire occurrence at lower and higher levels. Blanks in the histograms indicate no fires attacked in that particular ISI category. The increase of uncontrolled fires at higher ISI's is evident in all six graphs.

Slash fuels are associated with the highest fires spread rates and hence with the greatest number of escape fires. Aircraft drop lengths are longest in the open slash fuel; however, the high fire spread rates outdistance fire-line production more often than in any other fuel type.

Table 3. Summary of simulation results

Suppression method	Total No. of fires	No. of fires attacked	No. of fires controlled	Fires controlled / Fire totals	Fires controlled / Fires attacked	Expenditures			
						Total Cost	Cost/Total No. of fires	Cost/No. of fires attacked	Cost/Fi controll
Handcrews	485	447	287	59%	64%	$2,735,873	$5,641	$ 6,121	$ 9,533
204B	485	362	213	44%	59%	3,931,022	8,105	10,859	18,456
PBY Canso - amphibious	485	324	169	35%	52%	1,467,937	3,027	4,530	8,686
B-26	485	323	148	31%	46%	4,385,630	9,043	13,578	29,633
PBY Canso - land	485	354	106	22%	30%	4,008,941	8,266	11,325	37,820
206B	485	317	56	12%	18%	2,136,131	4,404	6,739	38,145

NUMBER OF CONTROLLED AND UNCONTROLLED FIRES

by

SUPPRESSION METHOD, INITIAL SPREAD INDEX (I. S. I.)

AND FUEL TYPE

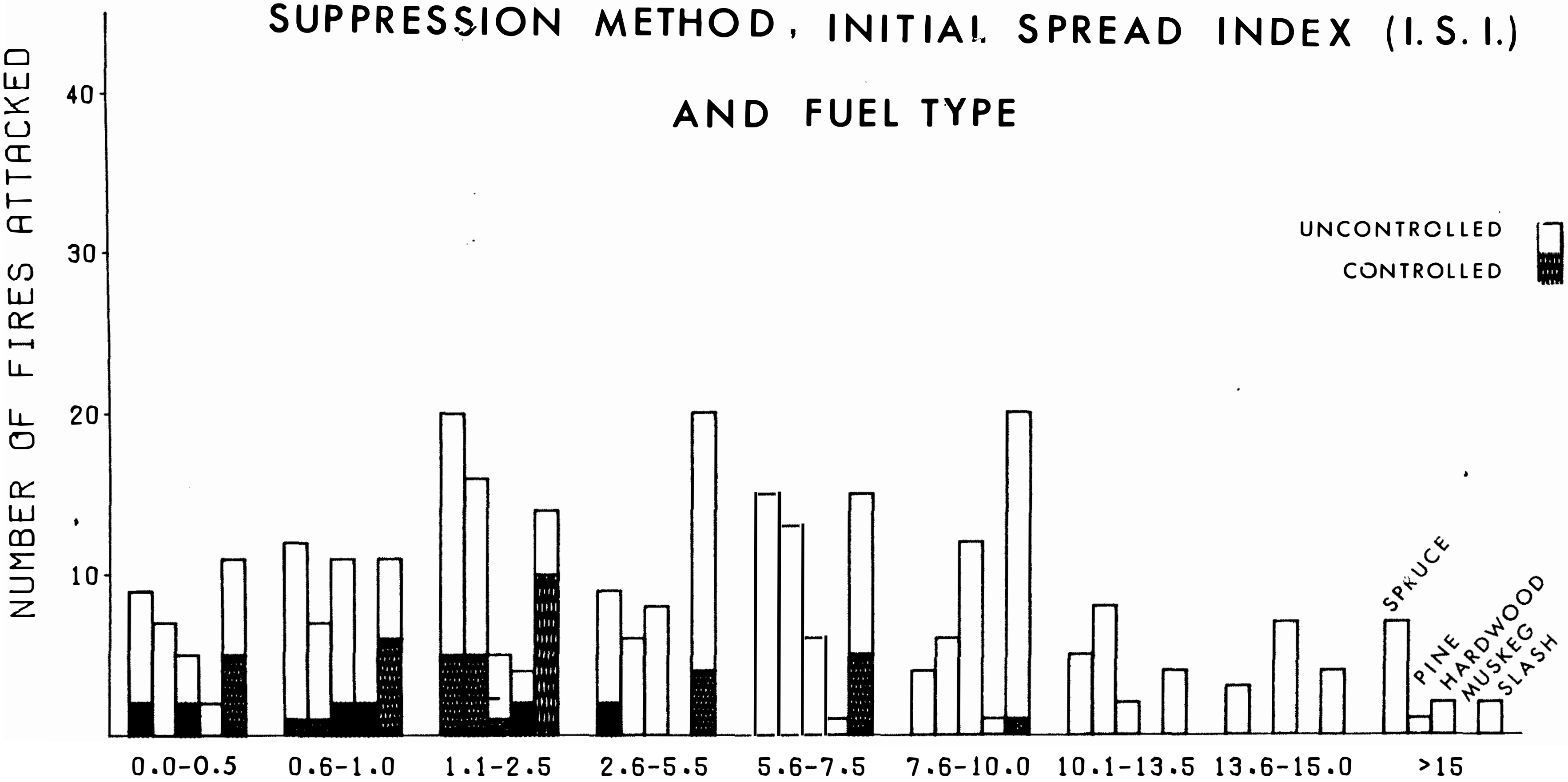


FIG. 6. HELICOPTER 206B

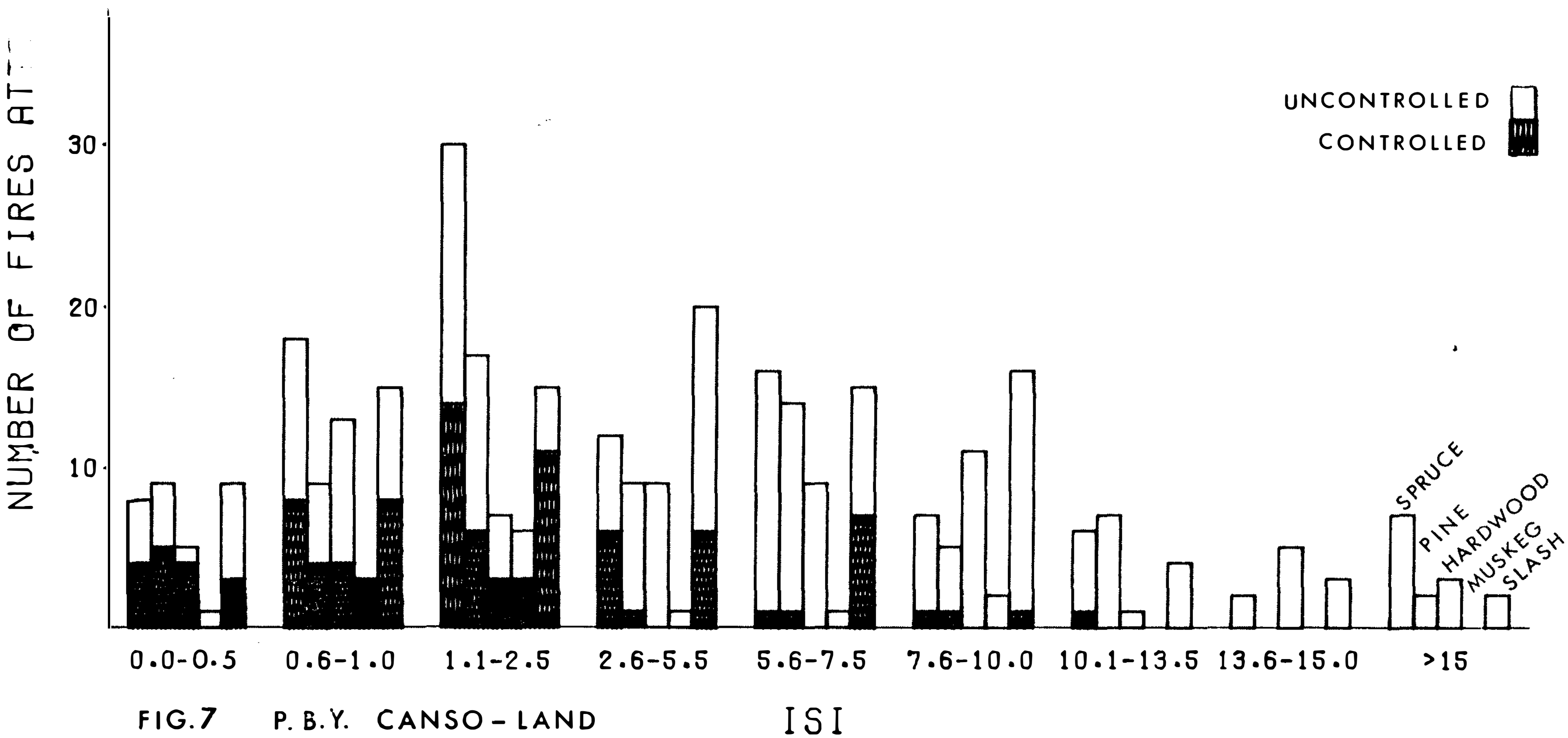


FIG.7 P. B.Y. CANSO - LAND

NUMBER OF CONTROLLED AND UNCONTROLLED FIRES

by

SUPPRESSION METHOD, INITIAL SPREAD INDEX (I.S.I.)

AND FUEL TYPE

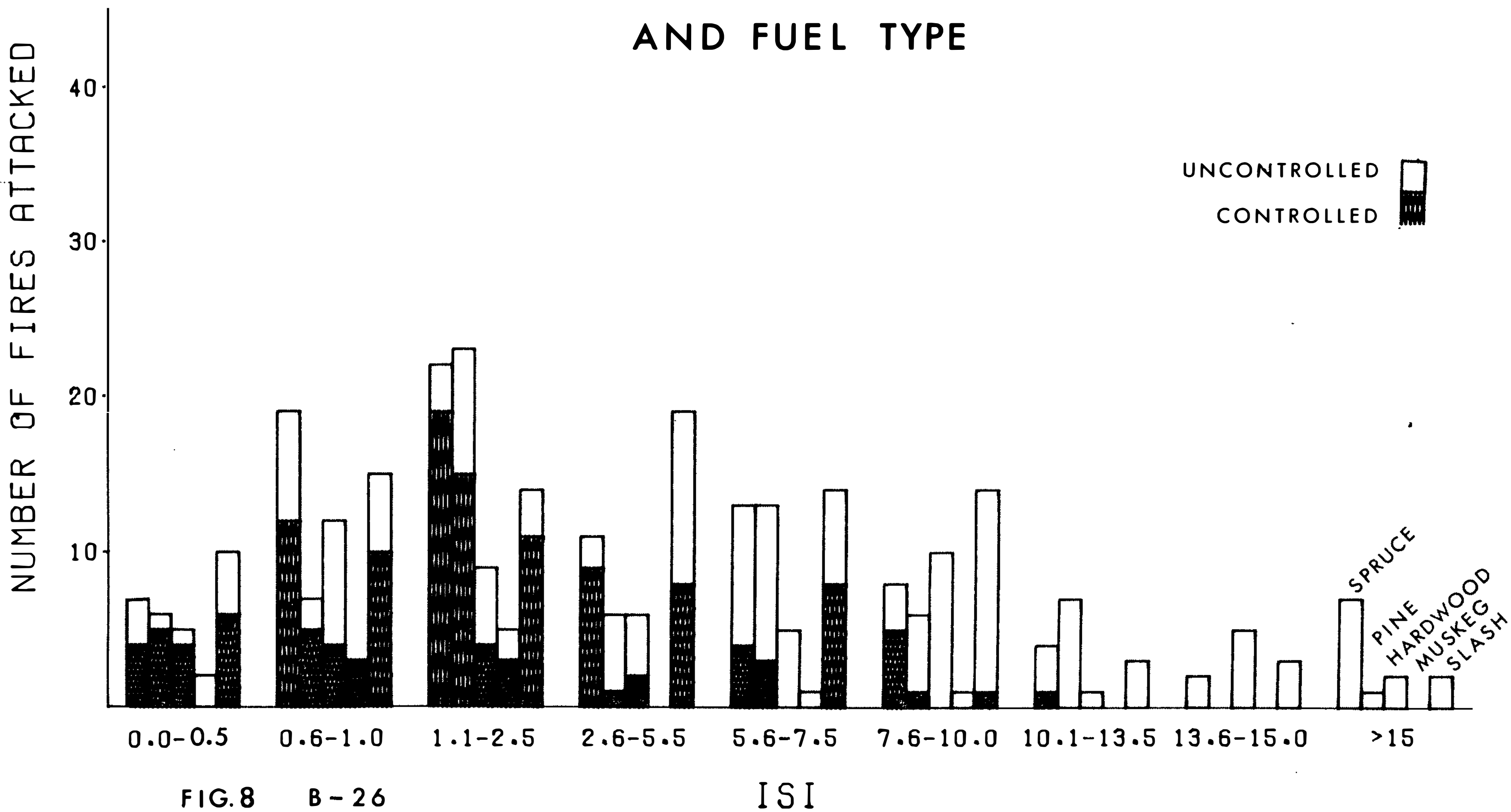


FIG.8 B-26

NUMBER OF CONTROLLED AND UNCONTROLLED FIRES

by

SUPPRESSION METHOD, INITIAL SPREAD INDEX (I.S.I.)

AND FUEL TYPE

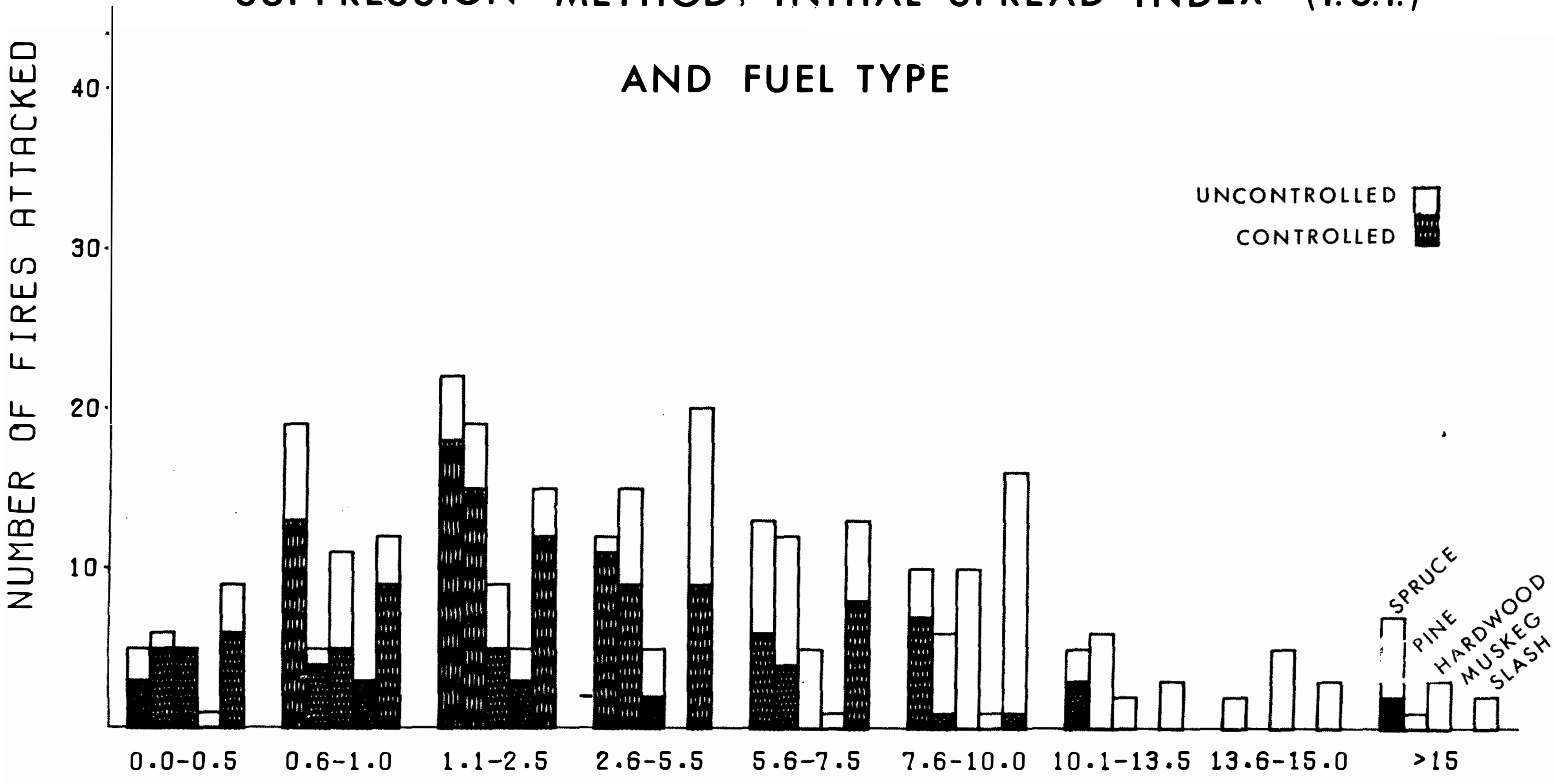


FIG.9 P.B.Y. CANSO-AMPHIBIOUS

NUMBER OF CONTROLLED AND UNCONTROLLED FIRES by SUPPRESSION METHOD, INITIAL SPREAD INDEX (I.S.I.) AND FUEL TYPE

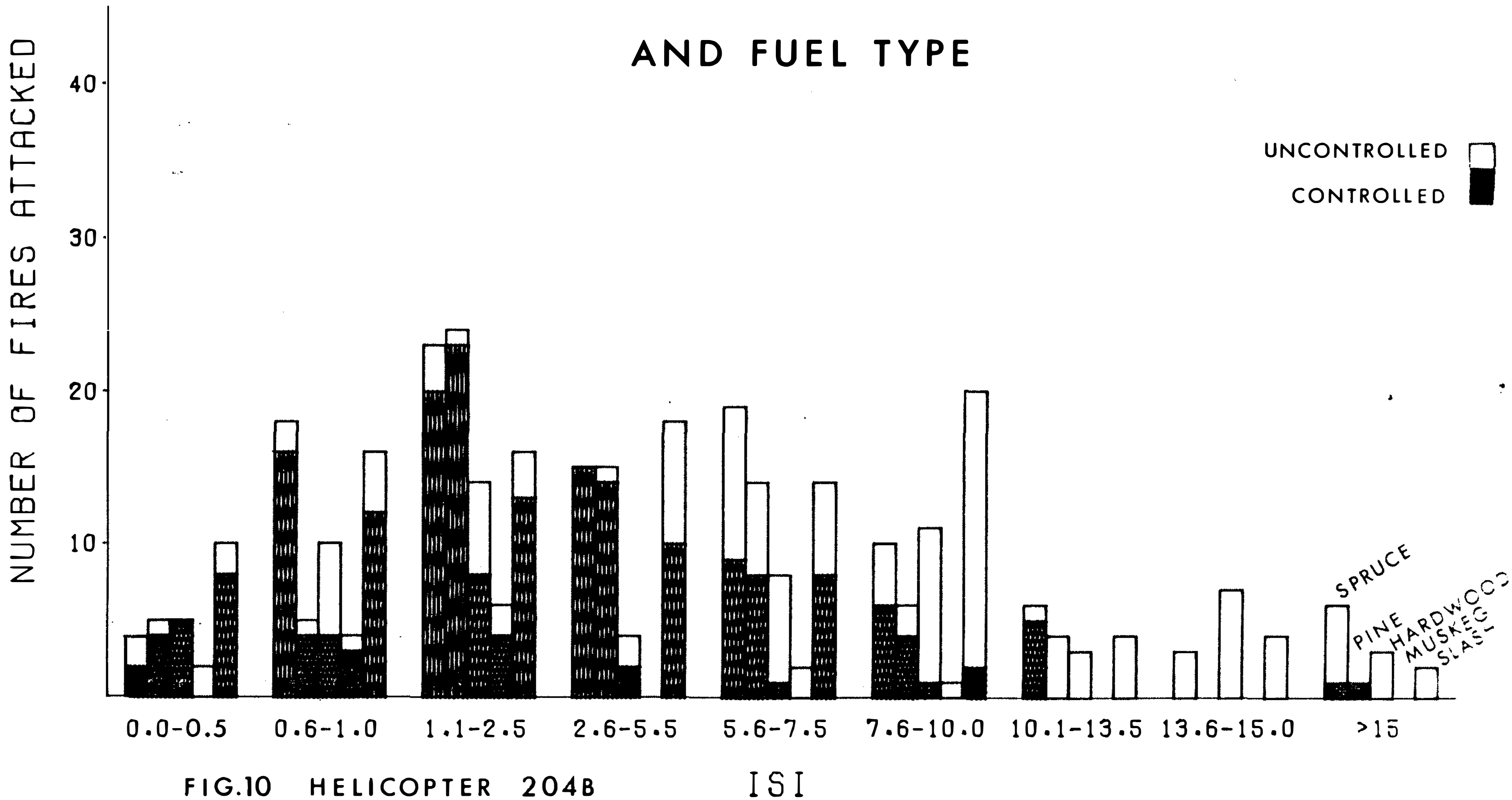


FIG.10 HELICOPTER 204B

NUMBER OF CONTROLLED AND UNCONTROLLED FIRES

by

SUPPRESSION METHOD, INITIAL SPREAD INDEX (I.S.I.)

AND FUEL TYPE

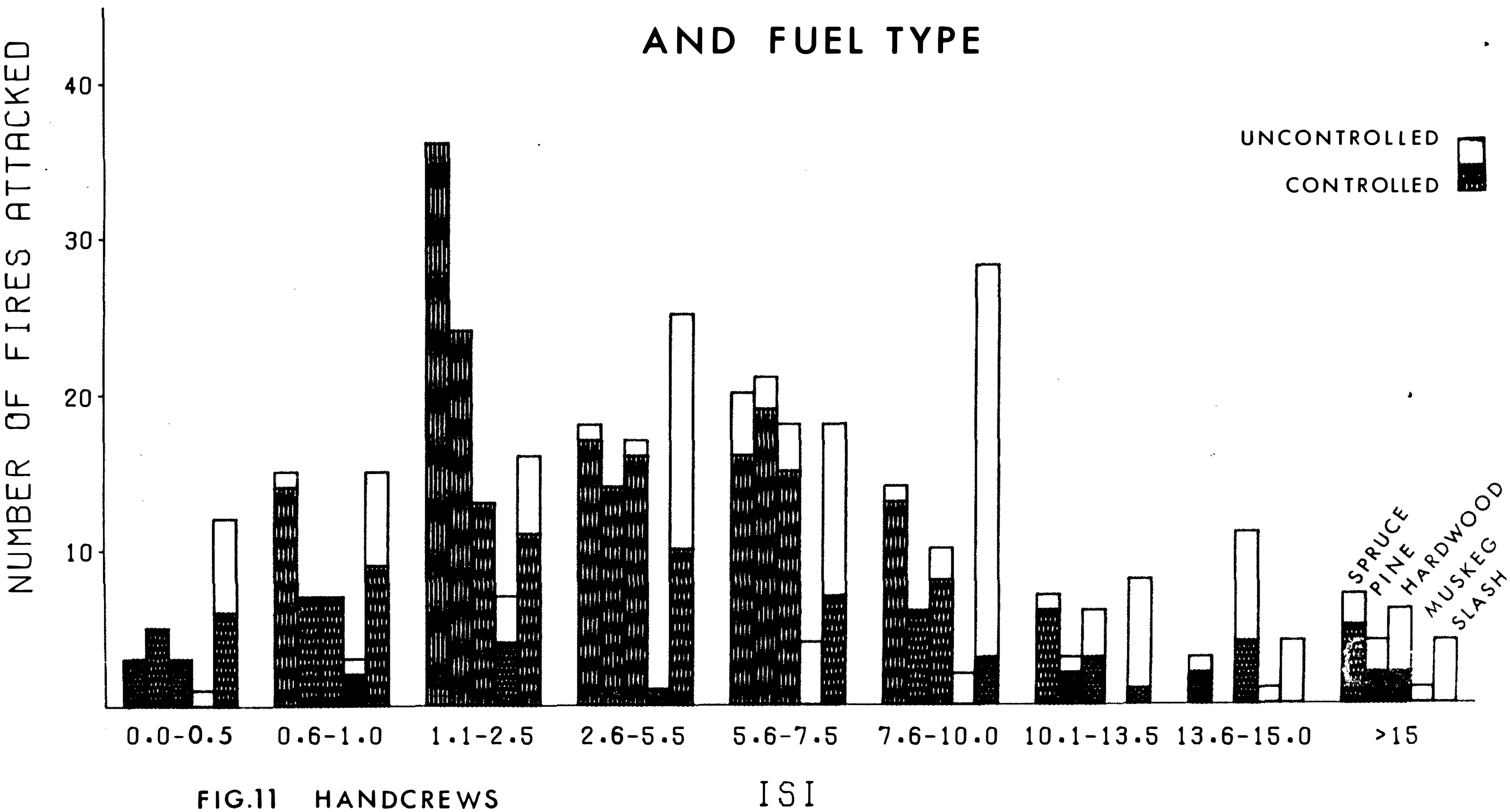


FIG.11 HANDCREWS

DISCUSSION

The 485 fires available for attack during the 10 fire seasons provided a variety of detection times, fire spread rates, travel distances and fuel types to sufficiently test performance of the six suppression methods. Although aircraft would not operationally attack all fires in any one fire season the simulation model is the ideal tool to examine both actual and theoretical suppression tactics. A full run of all six methods against the total 485 fires provided good reference data for future runs which will consider combinations of men and aircraft, and current cost figures.

Expenditures were simply a total of fixed and variable costs with no attempt to optimize. The large additional expense for land-based aircraft was for long-term retardant only, without incorporating capital costs for retardant bases and airstrips required to support air-tankers. Inflating retardant prices and the single-purpose use of land-based airtankers are serious economic factors which must be weighed against the merits of high airspeed and large capacity. A study is currently underway at the NFRC to determine the relative effectiveness of long-term retardant, short-term retardant, and water under operational conditions. The effectiveness data will assist in comparing the expenditures of land-based and amphibious airtankers and helitankers using retardants, water, and thickened water.

The success of a normal district complement of handcrews as illustrated in the model is reassuring. Men and handtools are still the basis of most fire control operations; and assuming that they will perform at a high calibre during the day and also through the night, their performance and economy is an incentive for emphasizing vigorous initial attack with crews wherever possible.

The high performance of the 204B helitanker is possible partly as a result of the short travel distances in the Whitecourt Forest, since airspeed can limit the role of the helitanker over long distances. Turbo fuel cost and supply could also be critical in more remote areas.

The exercise of developing a simulation model, particularly an interagency effort, is rewarding in itself. Both research and operational personnel benefited through the continuous exchanges, and in the research area four topics received increased priority:

(1) A major effort is underway at NFRC to standardize

computerize, and store detailed fire and weather data for large regions.

(2) Airtanker accuracy was assessed under operational conditions to provide better estimates of line building rates.

(3) The effectiveness of retardant, water, and thickened water will be studied on actual drops during high hazard burns.

(4) The operational performance of a 204B helitanker is being carefully monitored by the AFS.

The model is currently being reprogrammed to run handcrews and helitankers simultaneously, which requires adjusting fire growth on two fronts according to suppression activity. New cost data, accuracy data, and fire-line production data are available for future runs, and comparisons will be made to the benchmark results presented here. The initial work has served to relate common suppression methods to costs in one small, operational area; as well, the results can be used at the provincial planning level.

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APPENDIX I: Fire spread rates for five fuel types by fine fuel moisture code and wind classes (meters per minute)

		FINE FUEL MOISTURE CODE [1]						
FUEL TYPE	WIND km/h	60.0	70.0	80.0	85.0	90.0	95.0	99.0
	0.0	0.03	0.03	0.03	0.03	0.09	0.61	0.91
	8.0	0.03	0.03	0.03	0.06	0.30	1.52	3.05
	16.0	0.03	0.03	0.03	0.09	0.61	1.52	6.10
SPRUCE	24.0	0.03	0.03	0.03	0.12	0.91	6.10	12.19
	32.0	0.03	0.03	0.03	0.15	1.52	9.14	21.34
	40.0	0.03	0.03	0.03	0.24	2.44	13.72	33.53
	48.0	0.03	0.03	0.03	0.30	3.05	18.29	36.58
	0.0	0.03	0.03	0.03	0.06	0.15	0.30	0.91
	8.0	0.03	0.03	0.03	0.15	0.37	0.91	3.05
	16.0	0.03	0.03	0.06	0.24	0.52	1.37	4.57
PINE	24.0	0.03	0.03	0.06	0.30	0.79	9.14	13.72
	32.0	0.03	0.03	0.09	0.40	3.05	15.24	22.86
	40.0	0.03	0.03	0.12	0.52	7.62	22.86	36.58
	48.0	0.03	0.03	0.15	0.76	15.24	30.48	54.86
	0.0	0.03	0.03	0.03	0.30	0.46	0.91	1.52
	8.0	0.03	0.03	0.15	0.76	1.52	2.44	3.66
	16.0	0.03	0.03	0.30	1.50	3.05	5.49	7.62
HARDWOOD	24.0	0.03	0.03	0.61	2.13	4.57	7.62	12.19
	32.0	0.03	0.03	0.91	3.05	6.10	10.67	18.29
	40.0	0.03	0.03	1.22	3.64	7.62	13.71	24.38
	48.0	0.03	0.03	1.52	4.57	9.14	15.24	27.43
	0.0	0.03	0.03	0.03	0.15	0.30	0.46	0.46
	8.0	0.03	0.03	0.24	0.24	0.91	2.44	4.57
	16.0	0.03	0.15	0.46	0.91	4.57	6.10	9.14
MUSKEG	24.0	0.03	0.30	0.91	3.64	7.62	10.67	15.24
	32.0	0.03	0.46	1.52	6.10	12.19	24.38	36.58
	40.0	0.03	0.46	1.52	7.62	15.24	30.48	54.86
	48.0	0.03	0.46	1.52	8.53	22.86	53.34	56.20
	0.0	0.03	0.03	0.30	0.61	1.22	2.44	3.05
	8.0	0.03	0.03	0.91	3.05	6.10	12.19	24.38
	16.0	0.03	0.03	2.13	6.10	12.19	24.38	36.58
SLASH	24.0	0.03	0.03	3.66	9.14	18.29	33.53	42.67
	32.0	0.03	0.03	6.10	15.24	27.43	45.72	57.91
	40.0	0.03	0.03	7.62	24.38	39.62	57.91	70.96
	48.0	0.03	0.03	9.14	36.58	54.86	76.20	91.44

[1] Actual fuel moisture can be derived by subtracting the Fine Fuel Moisture Code from 101.

APPENDIX II: Fire Spread Adjustments

(a) Diurnal rate of spread adjustment.

Hour	% Adjustment Relative to 1600 h
0100	55
0200	55
0300	55
0400	50
0500	50
0600	50
0700	55
0800	60
0900	65
1000	70
1100	78
1200	82
1300	90
1400	95
1500	97
1600	100
1700	90
1800	80
1900	75
2000	68
2100	65
2200	60
2300	58
2400	55

(b) Slope and aspect adjustment.

	ASPECT	
Slope	South & West	North & East
	% Adjustment	
0	100	100
30	200	150
60	400	300
100	800	600

APPENDIX III: Model Variables

Uncontrolled Variables

The uncontrolled (fixed) variables are those of weather and fires. The take on a relatively wide range of values and are quantitative measures on inputs to the system.

a) Weather (Daily)

1. Wind
2. Temperature
3. Relative humidity
4. Precipitation

b) Fire descriptors

1. Location
2. Start time
3. Discovery time
4. Slope
5. Aspect
6. Fuel types
7. Nearest water source location

Decision Variables

Decision variables are those that the manager can control, altering them to obtain more desirable values for his measures of performance. In this model they are the parameters describing the initial attack system:

a. Tactic base locations
b. Tactic unit performance in each of five fuel types
c. Travel speed
d. Roundup time
e. Dispatch time
f. Cycle time
g. Costs of operation
h. Suppression units located at each base.

Intermediate Variables

Certain variables are designated as intermediate variables because they are relatively significant in the model. Usually they are measures of the individual units processed.

a) Fire behavior

1. Backfire spread rate = f (fuel type, fine fuel moisture code at nearest weather station, slope, aspect)
2. Headfire spread rate = f (same as (1) plus wind at nearest weather station)
3. Discovery area = f (backfire spread rate, headfire spread rate, start time, detection time)
4. Discovery perimeter = f (same as 3)

b) Final fire measurements

1. Final fire acreage = f (discovery area, discovery perimeter, contact time, headfire spread rate, backfire spread rate, unit productivity of tactic)
2. Contact time = f (location of fire, location of tactic base, travel speed, roundup time, dispatch time, discovery time)
3. Final fire perimeter = f (discovery perimeter, contact time, headfire spread rate, backfire spread rate, unit productivity of tactic)
4. Control time = f (discovery perimeter, contact time, discovery time, start time, headfire and backfire spread rates, unit productivity of tactic)
5. Final fire cost = f (time of control, time of detection, contact time, tactic costs)
6. Final fireline total = f (contact time, control time, unit productivity of tactic)

Measures of Performance

These variables are used by the system manager to rate the performance of the system-given values selected for the decision variables.

The change in these variables also indicates the sensitivity of the system to individual decision variables.

Performance was summarized under the following categories:

a) Controlled fires

1. Average final fire acreage by ISI group
2. Number of fires by ISI group
3. Average length of fire-line per fire by ISI group
4. Average cost per fire by distance group
5. Number of fires by distance group
6. Number of fires by time group

b) Uncontrolled fires

1. Average fire acreage at loss by ISI group
2. All of 1 to 6 above inclusive

c) Fires not attacked

This is simply a count of the number of fires that could not be attacked with the available resources.