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WILDLAND FIRE MANAGEMENT

VOLUME II: Wildland Fire Control 1985-1995

Results of the 1973 NASA/ASEE
Summer Faculty Fellowship Program
In Engineering Systems Design
At Stanford University and Ames Research Center

NASA Contract NGT-05-020-409 School of Engineering, Stanford University, 1973

TO THE READER:

This report is the product of an eleven-week summer workshop on systems design sponsored jointly by the National Aeronautics and Space Administration and the American Society for Engineering Education. The participants were nineteen faculty members from across the nation, representing various engineering disciplines plus law, economics, and computer science. Stanford University and Ames Research Center were the host institutions. The purpose was both to give the participants experience in systems engineering and to produce a useful study.

The problem considered was how to reduce the number and severity of California's wildland fires. The report is in two volumes.

Volume I presents a review of prevention methodologies and the development of cost-benefit models for making preignition decisions. Early in the study, it became clear that prevention as opposed to suppression was the most fruitful area for current efforts. Although the study is not complete or comprehensive, it is believed that the basic, systematic approach to the problem is not only valuable but crucial to obtaining further improvements in wildland fire management.

Volume II presents the preliminary design of a satellite-plus-computer earth-resources information system with potential uses in fire prevention and control. It is recommended that the "wildland fire community" as one potential user, take an active part in promoting and justifying the needs for such peaceful surveillance services. In addition, some suggestions are made for new organization and hardware.

We would like to acknowledge the invaluable information, advice, and encouragement that we received from the agencies responsible for wildland fire management: primarily, the U.S. Forest Service and the California Division of Forestry. In particular we thank Robert Weaver of the California Division of Forestry for tours and documents, enthusiasm and photography.

Some of our most valuable sources were the people who lectured during the first two weeks. They are listed here with their topics.

NATURAL RESOURCES AND FIRE IN CALIFORNIA	Dewitt Nelson, Chairman Natural Resources Management Corp.
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ORGANIZING FOR FIRE RESEARCH IN CALIFORNIA	Carl C. Wilson, Assistant Director Pacific Southwest Range and Experiment Station, U.S.F.S.
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APPLICATIONS OF DECISION ANALYSIS TO WILDLAND FIRE CONTROL	D. Warner North, Decision Analysis Group Stanford Research Institute

Finally, as director of the Stanford portion of the program, I would like to thank Dr. John Billingham, my co-director for his hospitality and the good services of Ames Research Center. Also, Linda Ploeg must be cited by all of us for continuing good cheer and good work as coordinating secretary.

William L. Verplank

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1973 NASA/ASEE
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Final Report

WILDLAND FIRE MANAGEMENT

VOLUME II: Wildland Fire Control 1985-1995

David R. Saveker, Editor

NASA Contract NGR-05-020-409
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Our thanks for continuing help, advice, and liaison with the various fire fighting agencies are especially made to Robert Weaver of the California Division of Forestry.

The participants who contributed to Volume II are R. Bernstein, J. Freeman, J. Hammon, R. Marlean, D. Saveker, G. Stickney.

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ABSTRACT

It is assumed that the State of California Resources Agency detailed recommendations by the ad hoc committees concerned with the California Wildland Fire Problem of 1970 will be implemented, and the interagency Firefighting Resources of Southern California Organized for Potential Emergencies, (FIRESCOPE) will have been operational for several years by 1985. We then address ourselves to the question, "What could be a logical technological extension of the Wildland Fire Management-State of the Art in the 1985-1995 era?" We assume that California's population will have increased to 30,000,000 people, that there will be further encroachment of structures in the wildlands by that time, and the public will demand a more effective suppression operation, if only to protect property in the future. This means that even though the firefighting agencies concerned in California now are successful (in better than nine out of ten wildfire incidents) in putting them out before they get large, this may not be good enough in the 1985 future. It is the seven or eight percent, that now turn out to be large fires, that we must take effective measures against in the 1985 scene.

We propose to make this improvement by adapting present advanced technology in the following respects:

(1) The creation of a national integrated information gathering system and processing system for making decisions through the use of earth resources scanning satellites, computers, displays, and communication links. We assume that such a system will be a national requirement which supervenes the wildland fire needs.

(2) A reorganized California Wildfire Control Force that is optimized to implement the decisions generated from the system technology.

(3) The adaptation and use of advanced suppression hardware to quench and contain the fires after the discovery of ignition.

The Study then proceeds to suggest satellite characteristics, sensor characteristics, discrimination algorithms, data communication techniques, data processing requirements, display characteristics, and costs in achieving an integrated wildland fire information system. A suppression doctrine is suggested that is premised on the information and decision generating capabilities achieved. A single unified firefighting organization is suggested as the operational force to suppress wildfires, and recommendations regarding new hardware for this control group, deployed as modular TASK FORCES, are made. A new concept for the logistic support of the deployed TASK FORCE is suggested.

Under the study concept, the national satellite system including ground support would be funded by the Federal government. If 16 satellites in near polar sun synchronous orbit at 6460 statute miles (10,382 km) altitude are used, we obtain about one hour interval coverage of the wildfire situation, we suggest communications via earth synchronous satellites already provided previously to the 1985 time era. There would be a large

amount of data made available for public use, and possibly the Department of Commerce could control the sale and distribution of it.

If we follow this assumption, the peaceful uses of the data could be sold internationally perhaps, or shared on a selected basis to treaty allies by edited presentations from the National Center. Once the data leaves the National Center to the Regional Centers, it could be measured and sold on some sort of a bit rate basis, time used basis, or other basis.

But this assumption also places the total user costing of the Satellite and Ground Support portion of the overall system out of the boundaries of this study.

Pricing the whole wildfire package in 1973 dollars:

(a) Summary total for Federal support in satellite and ground capability (This would be a separately justified national investment to bring the system to operational status in 1985.)

Satellite Flight Systems	$588,000,000
Ground Systems	175,000,000
	$763,000,000

(b) Summary total for State of California support: (Capital costs can be amortized over a 12 year period)

	Yearly	Capital
Command and Control	$ 600,000 (not incl. data cost)	$ 20,500,000
Suppression	143,200,000	57,600,000
Logistics	39,900,000	100,000,000 (assumes all new bases)
TOTALS	$183,700,000	$232,100,000

(c) Yearly operation and acquisition about $206,000,000. This compares to an estimated $219,000,000/year in California for total wildfire agency costs presently incurred.

A consideration of the projections about things that are feasible in the 1985-1995 period is invariably connected to the validity of the premises. And, we see that these premises in turn form the basic objectives of programs which support the achievement of the projected future situation. Perhaps a review of these major assumptions is worthwhile at this point in making a summation of the study:

(1) That a national satellite resources scanning system for peaceful purposes will be justified and operational in the 1985-1995 period.

(2) That a 10^8 bit/sec data rate and 10^{-6} to 10^{-7} radian angular resolution would be internationally acceptable from the military security standpoint, or

(3) That wildfire information could be sanitized out from a guarded or secure data source for "peaceful purposes."

(4) The Federal Government through joint agency action would justify the overall satellite system expenditures.

(5) That California would purchase a pro-rata share of such data for disaster control purposes.

(6) That a single wildland fire control organization under California State Division of Forestry cognizance would be created and maintained by sharing pro-rata owner's burden.

(7) That the California capital investment and operating costs for a wildland fire force can be equitably assigned by assessing the owners in order to finance the operation as suggested.

(8) That we are within technical bounds on state-of-the-art recommendations.

(9) That we can cut down on the number of men presently required for building fire lines by bringing to bear advanced technology.

(10) That we will have a California Wildland left to protect in 1985 that will be worth the effort.

Chapter I

INTRODUCTION

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Chapter I

INTRODUCTION

One of the primary objectives of the Stanford/ASEE/NASA summer study program is to encourage interdisciplinary systems design. That is, to select a problem that has a host of ramifications, to isolate and measure these parts and to suggest rational changes to soften the impact of their interactions for the benefit of our society. The wildfire threat to the State of California has proven to be a problem having the requisite social and technical complexity to keep a group of scholars busy for eleven weeks (and then some).

Several salient features became apparent after scanning wildfire data that were to influence the directions taken by the study group. Suppression statistics revealed that the present interagency firefighting effort was very good indeed, to the extent that if further money were to be spent without big interagency changes, the prevention area seemed the best place to invest now. How to frame this prevention strategy became a primary interdisciplinary design objective, and about two thirds of the group became interested in this major contribution.

Another point that was made during the early problem definition phase was that if you were going to improve suppression efforts, the capability to recognize potential fire spread and deploy suppression forces to the scene in response had to be considerably improved. It was the problem of taking the stitch in time. The response time improvement required suggested advanced technology.

The remaining third of the group proceeded to look into what advanced technology might do about future wildfires. A time frame of 1985-1995 was chosen as a good long range decade for projections. Why 1985? Well, it is one year after 1984, and we have the assurance from other sources that BIG BROTHER will be watching by 1984. It turns out that under the concept suggested, a good deal of fairly high resolution earth scanning is required. To the extent that things going on "outside" on a scale the size of a house, that are germane to the fire problem, are noted. But it is measuring that information regarding what might be going on a scale involving an individual "inside" the house is not required, and no invasion of privacy is suggested as needed in 1985, at least in this study, to solve the wildfire threat.

This chapter will set the design problem out in its general terms both technically and in the para military social context that a fire control organization implies. The remainder of the study will address segments of the problem in greater detail. The reader's indulgence is requested in the instance of some repetition of detail in chapters, but it was generally agreed by those conducting the study that each chapter should be able to stand on its own, if it were to be taken out of the report as a separate element.

A. Assumptions

The first volume of this report has dealt with the 1973 State of California needs in Wildland Fire Control. It was shown that added emphasis on prevention techniques would give the maximum cost benefits. The second section of this report deals with the future California needs (1985-1995), in Wildland Fire Control. Since we are dealing with future needs and a system design to satisfy these needs, some basic assumptions on the wildland fire problems, wildland fire control system, and report constraints in terms of design specifications are needed. These are:

(1) Prevention: Present general California wildfire control agencies' attitude and primary emphasis on suppression will be altered more toward a "prevention-suppression" fire control policy.

(2) Recommendations: The recommendation of the "Task Force on California's Wildland Fire Problem" will have been substantially implemented. (Cal State Resources Agency, 1972) (Tables 1.1 to 1.4).

(3) Protection Areas: The wildland protection areas (total 61,000,000 areas) will remain substantially the same (Figure 1.1).

(4) Population: The wildlands of California will experience an encroachment with population growth, and the figure of 30,000,000 people is used as a population guide for this study projection. This is roughly a gain of 9,000,000 over present population of approximately 21,000,000.

(5) Suppression Technology: "Firescope" will have been implemented and have been a qualified success. New concepts and technology will then be needed. These are set forth in Table 1.5 (S. Hirsch, 1973).

(6) Economics: There are no specific "budget restrictions" but a cost estimate to bring the proposal into production must be a part of the design consideration.

(7) Feasibility: All design items proposed must be technically feasible in accordance with the "state of the art."

B. System Objectives

The overall objectives of the system are to suggest a design for:

(1) An integrated information gathering and processing system for making decisions.

(2) An organization designed to optimally implement the decisions.

(3) An enhanced role for suppression apparatus technology.

An information gathering and processing system is required to implement the following objectives:

(1) Fire Detection: To swiftly detect and estimate the size of a fire.

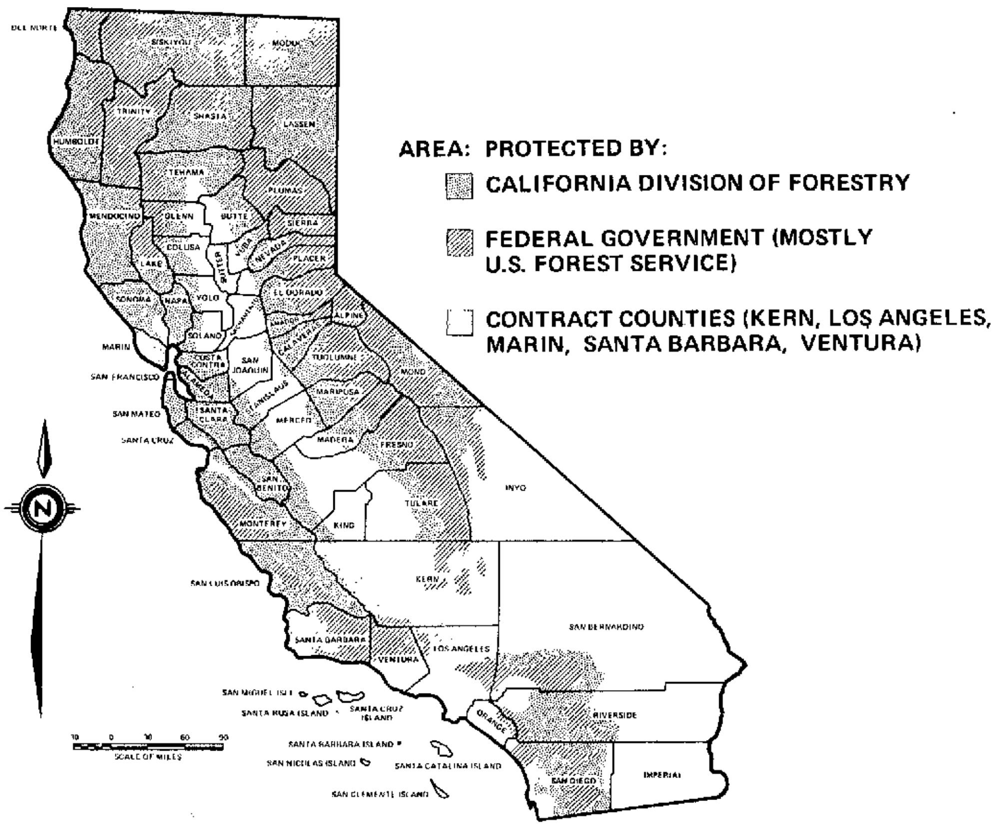

Figure 1.1 Areas of Wildland Fire Protection Responsibility in California

Table 1.1

RECOMMENDATIONS TO SOLVE CALIFORNIA'S WILDLAND FIRE PROBLEM
FIRE PREVENTION

A1. PROVIDE FIRE PROTECTION STANDARDS FOR LOCAL GOVERNMENTS.

A2. DEVISE A "WILDLAND HAZARD ALERT" SYSTEM.

A3. PROVIDE PROPER EQUIPMENT TO SOLVE INCENDIARISM PROBLEM.

A4. MAKE MORE EFFECTIVE USE OF LAWS TO CURB INCENDIARISM.

A5. SUSPEND DEBRIS BURNING DURING CRITICAL WEATHER.

A6. CURTAIL EQUIPMENT USE DURING CRITICAL WEATHER.

A7. PROVIDE ADEQUATE NUMBER OF FIRE PREVENTION PERSONNEL.

A8. INTENSIFY FIRE PREVENTION PATROLS DURING CRITICAL WEATHER.

A9. IMPROVE POWER LINE INSPECTIONS.

A10. IMPROVE POWER UTILITY OPERATIONS DURING CRITICAL WEATHER.

A11. INSTALL LOW VOLTAGE TRANSMISSION LINES UNDERGROUND.

A12. DETERMINE ROADSIDE FIRE CAUSES AND LOCATIONS.

A13. ESTABLISH A FIRE PREVENTION ACTION COMMITTEE.

Table 1.2

FUEL MANAGEMENT & HAZARD REDUCTION

B1. PREPARE HAZARD REDUCTION GUIDES.

B2. USE PRESCRIBED BURNING TO REDUCE FUEL HAZARDS, WITH DUE CONCERN FOR ENVIRONMENTAL QUALITY.

B3. PROVIDE FUELBREAK AND GREENBELT STANDARDS.

B4. INCREASE MANPOWER FOR BUILDING FUELBREAK AND OTHER FACILITIES.

B5. GIVE MORE EMPHASIS TO FUEL HAZARD REDUCTION PROGRAMS.

B6. INVESTIGATE LIABILITY INSURANCE REQUIREMENTS FOR PRESCRIBED BURNING.

B7. DETERMINE LEGAL ROLE OF PUBLIC AGENCIES IN PRESCRIBED BURNING ON PRIVATE LAND.

B8. DEMONSTRATE FUEL MANAGEMENT TECHNIQUES.

B9. IMPLEMENT FUEL MANAGEMENT PROGRAM IN STATE PARK AND RECREATION SYSTEM.

B10. IMPLEMENT HAZARD REDUCTION PROGRAMS ON COUNTY ROADS.

B11. STRENGTHEN REQUIREMENTS FOR HAZARD REDUCTION AROUND STRUCTURES.

B12. STRENGTHEN RESEARCH IN "FIRE RESISTANT" PLANTS.

B13. FIND NEW WAYS OF CONTROLLING BRUSH GROWTH.

B14. SUMMARIZE FUEL MANAGEMENT & HAZARD REDUCTION INFORMATION AND RECOMMEND ACTION PROGRAMS FOR EACH VEGETATION TYPE.

B15. ESTABLISH A FUEL MANAGEMENT AND HAZARD REDUCTION ACTION COMMITTEE.

Table 1.3

ZONING, SUBDIVISION CODES, LAND USE

C1. HELP LOCAL GOVERNMENTS ESTABLISH WILDLAND FIRE PROTECTION STANDARDS.

C2. PROVIDE RESOURCE DATA AND FIRE PROTECTION CONSULTING HELP TO LOCAL GOVERNMENTS.

C3. REQUIRE LOCAL GOVERNMENT TO CONSIDER LAND USE IN TERMS OF FIRE AND OTHER HAZARDS.

C4. STRENGTHEN STATE PLANNING LAW TO PROVIDE FOR BETTER FIRE PROTECTION.

C5. REQUIRE LAND DEVELOPERS TO PROVIDE AN INTERIM FUEL MANAGEMENT PROGRAM.

C6. PROVIDE ON SITE ACCESS TO SWIMMING POOLS FOR FIRE PROTECTION.

C7. ESTABLISH A FIRE PROTECTION IN LAND USE PLANNING ACTION COMMITTEE.

Table 1.4

BUILDING CODES, CONSTRUCTION, MATERIALS REQUIREMENTS

D1. PROVIDE STANDARDS FOR BUILDING LOCATION AND DENSITY IN THE WILDLANDS.

D2. REQUIRE CERTAIN BUILDING SPECIFICATIONS IN THE WILDLANDS.

D3. DEVELOP STANDARDS FOR NUMBERING BUILDINGS.

D4. ESTABLISH A BUILDING CONSTRUCTION ACTION COMMITTEE.

FIRE CONTROL

E1. DEVELOP A FIRE COMMAND STRUCTURE.

E2. UPDATE FEDERAL RURAL FIRE DEFENSE PLAN.

E3. UPDATE STATE FIRE DISASTER PLAN.

E4. IMPROVE FIREFIGHTING COMMUNICATIONS SYSTEMS.

E5. DEVELOP NEW TOOLS FOR THE INDIVIDUAL FIREFIGHTER.

E6. DEVELOP NEW TECHNIQUES TO IMPROVE TACTICAL USE OF FIREFIGHTING FORCES.

E7. IMPROVE USE OF STATE AND FEDERAL MILITARY FORCES.

E8. PROVIDE FIRE PROTECTION STANDARDS FOR ROADS BUILT IN THE WILDLANDS.

E9. PROVIDE FIRE PROTECTION STANDARDS FOR WATER SUPPLY SYSTEMS.

Table 1.5

FIRESCOPE MAJOR TASKS 1975 — 1985	WILDLAND MANAGEMENT 1985 — 1995
PART I – COMMAND POLICY AND OPERATIONS	
* DEFINE ROLE OF SYSTEM AND IDENTIFY CONSTRAINTS ON AGENCY PARTICIPATION	SINGLE FORCE ASSUMPTION
* DEVELOP AND TEST FUNCTIONAL CONCEPTS AND OPERATIONAL REQUIREMENTS	FURTHER MODIFICATIONS
* PROVIDE DESIGN CRITERIA	ADVANCE DESIGN CRITERIA
* PROVIDE ASSISTANCE IN IMPLEMENTATION AND TRAINING	NO ATTEMPT
PART II – COMMAND SYSTEM DEVELOPMENT	
* PERFORM TECHNICAL EVALUATION OF CONCEPTUAL REQUIREMENTS	NEAT DECADE CONCEPT
* DETERMINE STATE-OF-ART OF EXISTING APPLICABLE TECHNOLOGY	NEAT DECADE CONCEPT
* INTEGRATION OF ON-GOING RESEARCH AND DEVELOPMENT OF EFFECTIVE LARGE FIRE SPREAD MODEL	NO ATTEMPT
* DESIGN OF COMMAND SYSTEM CONFIGURATION BASED ON PART I CRITERIA	SINGLE FORCE ASSUMPTION
PART III – COMMAND SYSTEM FABRICATION AND INSTALLATION	
* PROCURE AND FABRICATE HARDWARE	NO ATTEMPT
* INSTALLATION AND CHECKOUT	NO ATTEMPT
* OPERATIONAL TRAINING	NO ATTEMPT
* IMPLEMENT SYSTEM	NO ATTEMPT

(2) Fire Spread Models: To generate accurate parameters for input into the fire spread equations.

(3) Prescribed Burn: To predict the time and locations for effective prescribed burning.

(4) Let Burn: To designate let burn areas from data on land use and value, structures, and fire spread models.

(5) Seeding and Planting: To accurately locate areas in need of seeding and planting by types, from vegetation cover and land use.

(6) Fuel Break Location: To accurately locate all types of fuel breaks for mapping.

(7) Structure Inspection: To determine the location, roof type, and vegetation clearance, by types, of all wildland structures.

(8) Burning Permits: To generate accurate meso-FDR's or fire spread predictions for the issuing of burning permits.

(9) Fire Suppression: To generate quickly-and-accurately the location, area, and a prediction of the fire spread to the closest agency with proper dispatch instructions for controlling the fire.

(10) Statistics: To build a data file on land use and fire control for future land management decisions.

In order to accurately accomplish the preceding objectives, the following parameters must be measured or calculated for every area subsection.

(1) Fuel Type

(2) Fuel Moisture

(3) Fuel Density

(4) Cartography

(5) Land Usage

(6) Weather

(7) Fuel Ignition

The fuel type data is needed as input to fire spread models, prescribed burns, let burn, seeding and planting, and landscape around structures. The most sensitive aspect of the fuel types, or the intermingling of fuel types, is in the generation of an accurate fire spread model. It is assumed the error in the mathematical model of fire spread by 1985 will be minimized. Therefore, fuel inhomogeneity will be a sensitive input. Generation of fuel types for a 10 m^2 area would therefore be an important parameter of the information gathering system. This may be accomplished by land vegetation surveys and/or airborne multispectral scanning.

The fuel moisture and fuel density data have the same basic requirements and uses as the fuel type data. These data may be gathered and filed at the same time as fuel moisture data. The only added requirements, are the fuel density, the ratio of live fuel to dead fuel, and the diurnal variation of fuel moisture. Fuel moisture will vary 10% throughout the day (Schroeder, 1970). This will be a maximum at dawn and a minimum around 3 p.m. In order to extrapolate fuel moisture at any time of the day, at least 3 samples per day must be taken.

The cartography databank must contain roads, fuel breaks, fire breaks, structures, and terrain. These data are needed for all the information objectives except fire detection. Initially data must be collected and updated yearly. This may be done by land surveys or airborne scanning.

Land usage may be obtained from present governmental agencies and selected land surveys.

Weather is one of the most critical parameters for input into the information objectives. It is used for all objectives but fire detection. The generation of macro-weather is well accomplished. The generation of micro-weather from extrapolation of remote weather station data is still an art. The most critical aspect of the weather, as shown by the first section of this report is wind velocity and direction (wind vector).

In order to extrapolate this micro-weather information, more remote weather stations are needed with research on extrapolation of this data due to cartography. The cartography databank will facilitate this.

As shown in the first section of this report, detection of incendiary fires or those in populated areas is not a problem in the majority of cases. Lightning fires may go undetected for longer periods. The present system of detection plus specialized detection systems for spotting and lightning starts will accomplish the fire detection objective. This may be enhanced with an expanded "Firescan"-"Firescope" system or by satellite scanning systems.

C. System Concept

There are three ways to generate the information requirements for system parameters. They are ground surveys, airborne scanning, and satellite scanning. Ground surveys are considered infeasible because of time and manpower limitations. Therefore, airborne and satellite scanning are examined.

It is possible to use high altitude aircraft, such as the U-2 for ground scanning. Since fuel type, fuel load, and fuel moisture must be scanned repetitively (Colwell, ERSS), a minimum of 14 flights per year is necessary. This would include flights every second week during vigorous growth periods. Cartography would be sensed at the same time, but the data would only be updated yearly. This, in conjunction with remote weather stations telemetering information to a commercial relay satellite and a large scale computer for land usage data, plus scan data, would give a non-real-time information system. The present fire detection system with an updated "Firescan" would be an adequate quasi-real-time system.

The cost of such a system, without the ground stations, are estimated, using 1973 dollars, and a U-2 aircraft (NASA, 1973).

U-2 Scan

Area	700 × 70 miles (coast) 400 × 90 miles (eastern side)
Frames	50 × 5 (coast) 29 × 7 (eastern side)
Cost/Frames	$30 × 453 = $13,590
Cost/Plane	$1,000/hr × 14 hrs = $14,000

For fuel sensing, a three color scan is necessary. Therefore, the total cost per

Single U-2 Flight Cost	$54,770
Firescan Cost ($40/hr, 150 hrs)	60,000

Yearly cost would be

U-2 Flight Cost (10 flights)	$547,700
Firescan ($40/hr, 150 hrs)	60,000
Optical/Digital Converter (10 yr life) . .	10,000
Total yearly cost	$617,700

This would be an airborne system dedicated to the California wildlands with no other major users.

A satellite ground scanning system has, as of 1973, two major prototype possibilities. A geosynchronous satellite or GOES type, stationary at 35,872 km (22,260 statute miles) over California; and/or an ERTS (Earth Resources Technology Satellite) type system which is sun-synchronous at 892 km (555 statute miles) if it is below the Van Allen Belt, or about 6460 miles (10,382 km) if it orbits above the heavy particle region of the Van Allen Belt. The geosynchronous satellite system could give continuous monitoring, but the ground resolution would be approximately (assuming 4×10^{-7} angular resolution by 1985) 20 meters. The sun-synchronous satellite system, such as ERTS, would furnish adequate resolution (approximately 3 meters) but is discontinuous. The present ERTS satellite has the same ground orbit every 18 days. In the wildland fire problem this would be adequate for cartography, less than optimum for fuel conditions, and useless for fire detection. The present single satellite ERTS system cost $160,000,000. Any satellite system for California Wildland Fire Control exclusively, is also cost prohibitive.

The present ERTS system has generated two major results (NASA, SP-327)

(1) A satellite system is demonstrably cost effective for scanning earth resources.

(2) There is an international need for earth resources scanning.

The ERTS-B satellite is now being readied for launch. Twenty-five countries have submitted requests for data from this satellite. It is evident that some variety of an ERTS-"N" satellite system most probably will be in orbit in 1985. One of the major changes envisioned in this future system is a quasi-real time observational capability. The Department of Agriculture, Coast Guard, Environmental Protection Agency, National Oceanic and Atmospheric Administration, and others all need faster sampling rates than provided by present data sources.

The second major change envisioned in the probable ERTS system for 1985 is the orbital altitude. The present low altitude orbit does not allow sufficient sampling time over a given target. The increase in data, per sample, necessitates a longer sampling time per frame. This means an increase in orbital altitude. The Van Allen belt makes it necessary to go from the present fairly low orbits to an altitude of 6460 statute miles (10,382 km). The resolution, at this altitude in 1985 would be approximately 10 m^2.

This altitude furnishes the ground pattern shown in Figure 1.2 (Evans, C.P. 1973). One satellite will furnish scan data over any given target every 24 hours. The width of the ground scan is approximately 3,000 nautical miles (5590 km) (50° satellite scanner). This provides the necessary overlap on north-south passes. A 16 satellite sun-synchronous system at the higher orbit will give world wide coverage every hour.

The cost of such a satellite system is estimated in this study to be approximately $763,000,000 (Ch. IX). The economical justification of this money is based upon:

(1) Economic benefits of ERTS-A

(2) Future "Earth Resources" data needs

The ERTS-A has had major economic returns (ERTS-A Symposium, 1973) and has justified the ERTS-B System. Future earth resources data needs are similarly justified with the added technical requirement of better resolution, longer sampling times, and a shorter sampling period.

The Navy and Air Force have the same basic specifications for world wide surveillance. The Navy is presently developing a system which involves 27 satellites in sun synchronous orbits at 8,000 miles. They have

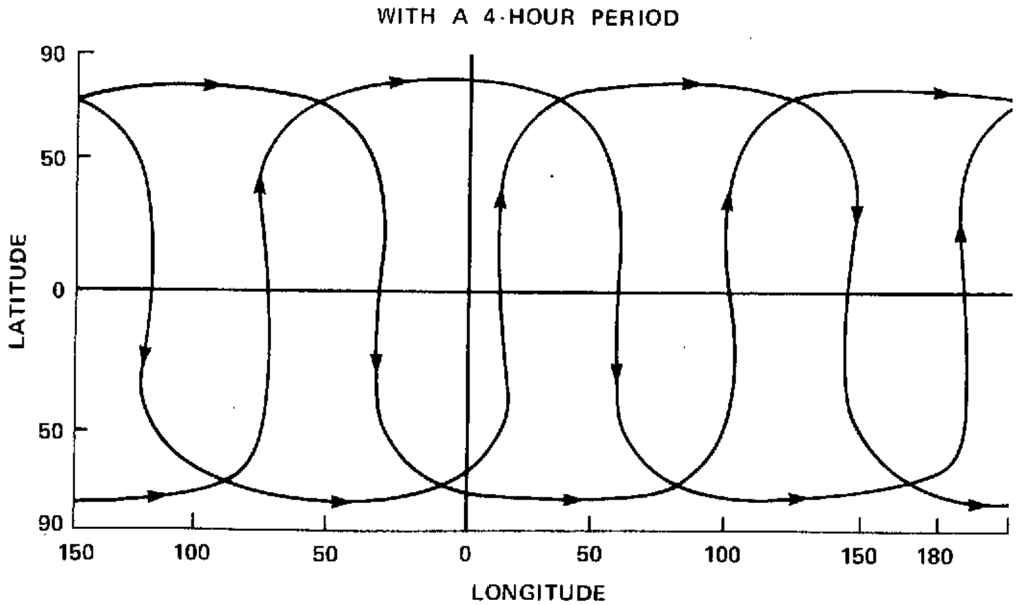

Figure 1.2 24 Hour Ground Track for Sun Synchronous Orbit Within a 4 Hour Period

plans for an extended test of this system (Klass, 1973) for a potential 1977 implementation. The resolution and sampling interval is similar to that required for the earth resources scanning suggested in this study.

The "ERTS-1985" satellite system is envisioned to be a quasi-real-time (maximum data delay of 1 hour) scanning system used by many international agencies. The time-sharing aspect of this system, with Wildland Fire Control agencies as one time-sharer among many is depicted in Figure 1.3.

The previous specifications and needs suggest a 1985 ERTS system with the following parameters:

Use	international
Orbit	16 sun synchronous 2 geosynchronous repeater relays
Resolution	3 meters
Scan	50° (3,000 nautical miles)
Sampling Rate	hourly
Cost	$763,000,000 + ground stations

The California Wildland Fire Control Agencies would receive the satellite data and process it for both passive prevention and active suppression fire control purposes. The data would be received digitally, and thus an optical to digital converter would not be needed. The percentage of satellite operational costs paid for by California would depend upon the number of other users, their percentage share of data, the federal government, the projected life, and other considerations.

Present systems, such as the Pioneer Satellite, have demonstrated a three year life. Satellite elements in the 1985 ERTS system could be assumed to have at least this life. Shuttle capability affording manned servicing and electronic redundancy should extend individual satellite performance indefinitely.

The State of California would, extrapolating from the coverage offered by current ERTS-A, use a maximum of 1% of the generated data. This includes data for California on wildland fire control, coast-monitoring, urban planning, pollution monitoring, and agricultural status. The projected capital cost share for the State of California, under the present assumptions, would be:

$$\frac{(.01)\ (763{,}000{,}000)}{3}$$

or $2,543,000, per year, amortized in three years.

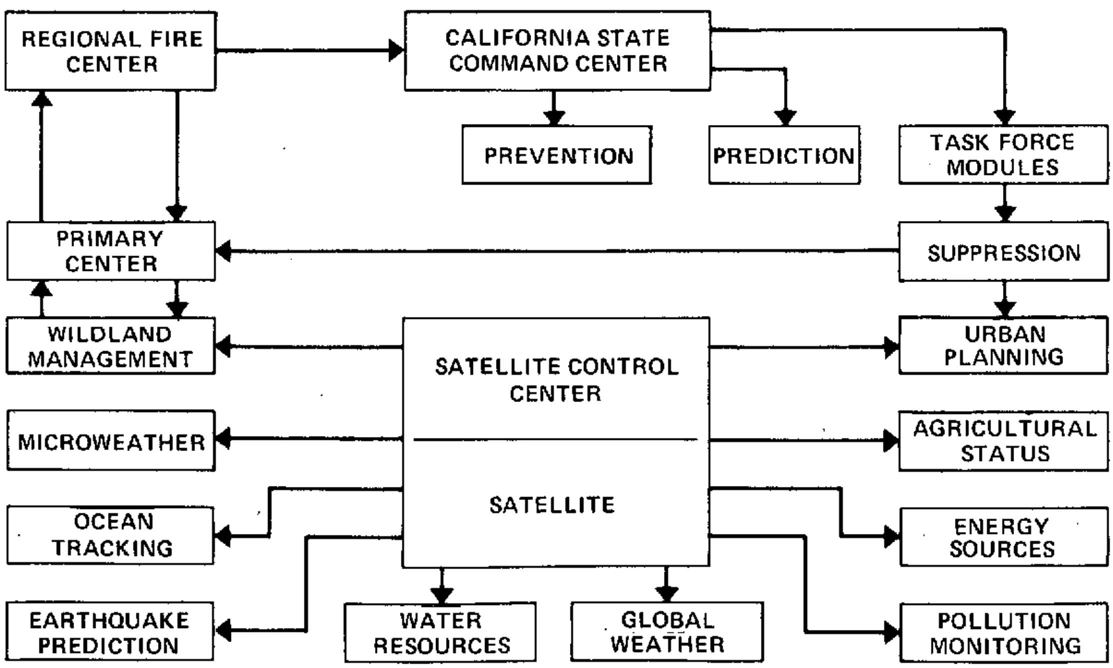

Figure 1.3 Functional Diagram of Satellite Data Gathering System

This would be a capital cost share based on geographical coverage alone of a world wide system, discounting any other users of the same information. However, the ERTS-1985 system would be more useful for many applications (see needs, Chapter II) and thus many more users with greater cost benefits to the State of California are anticipated. With more users and federal participation, this capital amortization cost would be proportionally shared to the advantage of California.

Because of the advantages for the State of California and the single user aspect of U-2 scanning, we have assumed that the State of California, and the California Wildland Fire Control Agencies in particular, will be an ERTS-1985 user. The information system detailed in this report therefore relies on a satellite scanning system.

D. Suppression and Organization System

Wildland fire suppression technology is divided into two categories: passive and active. The passive category includes fuel removal, backfiring and backburning and the use of fire retardant chemicals. The active category refers to direct attack with water, chemicals, dirt, etc., from ground and air. Suppression technology in the passive area will include faster fuel removal and more efficient fire retardant chemicals by 1985. Faster fuel removal may be accomplished by vehicles with a flail head or an individual with a compressed air activated set of pruning shears or even line charge explosives. Backfiring and backburning are proven procedures with little capability for technology enhancement. Retardant measures and chemicals will have increased effectiveness due to chemical research and delivery technology from ground and air. Suppression Technology in the active area will increase the individual effectiveness of the 1985 wildland fire fighter. This will be accomplished with advanced technology fire fighting vehicles which have 55 mph highway capability, and off the road 60% slope, 30% side-slope capability. Integrated into such vehicles will be better apparatus for fire suppression. Greater use and effectiveness of helicopters and other aircraft are also anticipated by 1985 (Chapter VI).

The wildfire suppression forces will have been organized and deployed to meet the 1985 potential destructive fire threat. The suggested initial attack capability will have been arrived at after a consideration of values and fire danger to meet the 1985 demographic situation that mixes wildlands, people, and structures on the baseline geographical and cartographic reference system. This "task force" organization concept is employed through the suggested use of standard "module units" that are dispatched in designated organizational packages to the scene. Dispatching doctrine is based on scrambling multiple, integrated units early to maximize chances for early suppression.

The present California Division of Forestry organization for initial attack fire and extended attack fire situations are compared to the suggested Task Force organizations discussed in greater detail in Chapter V (Figures 1.4 and 1.5).

One of the real time functions of the information gathering system would be to measure the actual spread rate of the fire. This would be

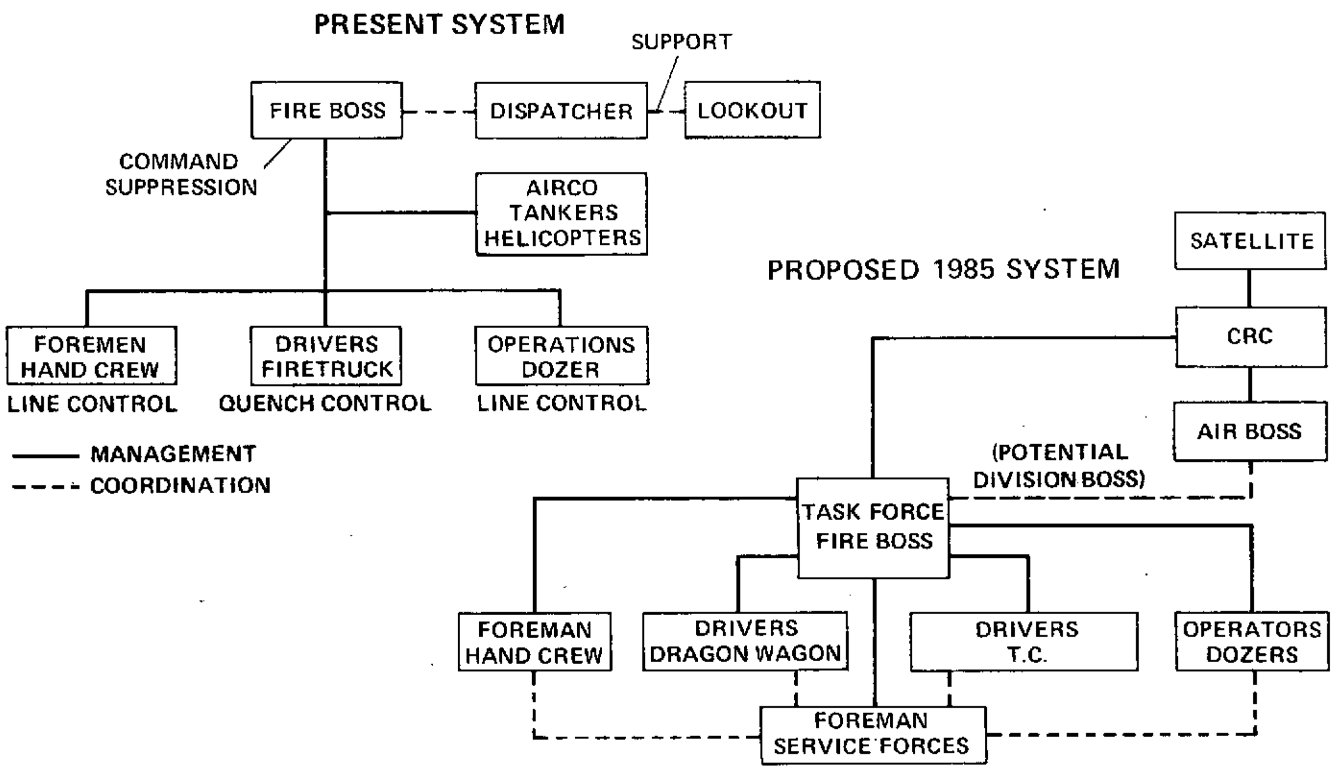

Figure 1.4 Initial Attack Fire Organization

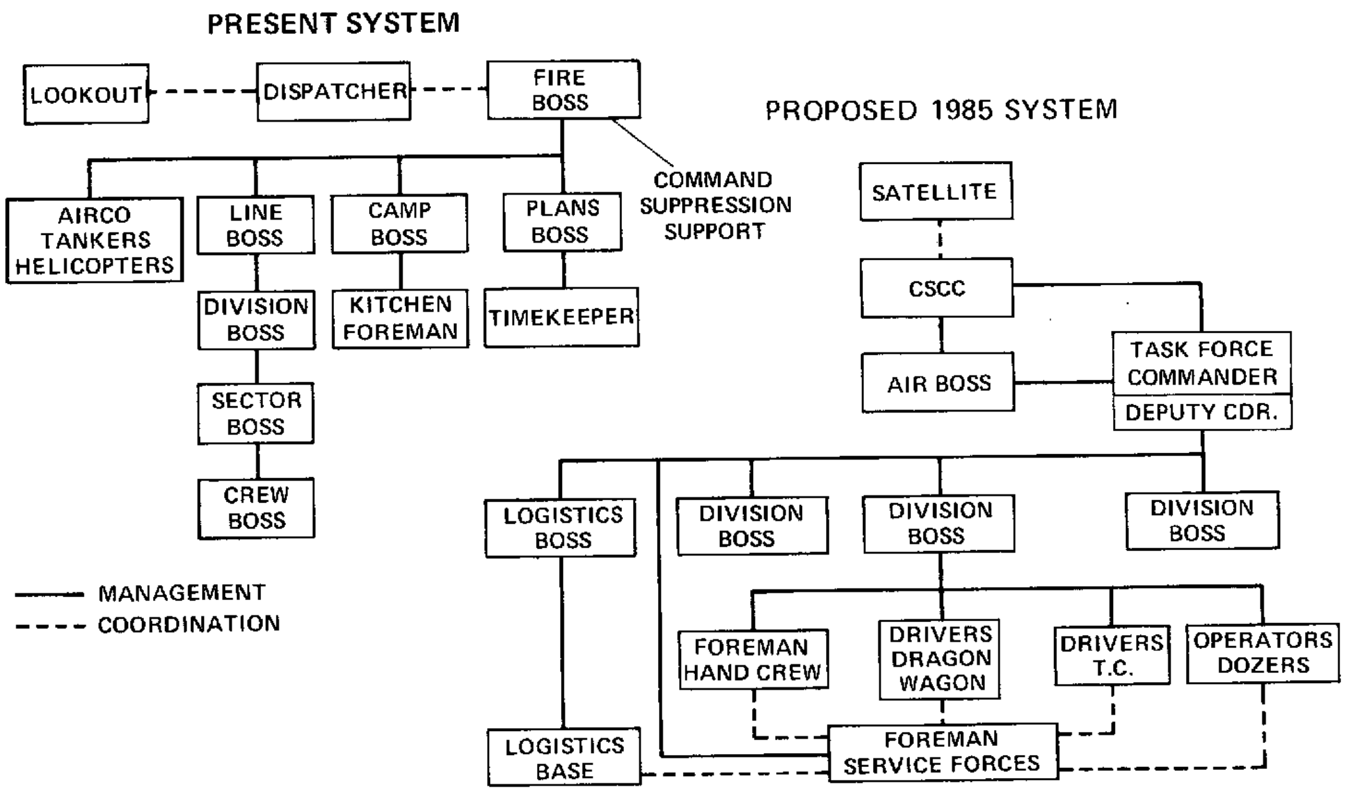

Figure 1.5 Extended Attack Fire Organization

compared to the predicted spread rate in order to ascertain the degree of "control" of the fire. If it were getting out of hand, an earlier dispatching of supporting "task forces" would be achieved without decision delay. Task force response times to operational sites would be a matter of computer memory storage, and the deployment of task forces to meet the situation would be a part of the computational interval, updated to predict fire boundary control. The computer should be able to indicate whether there is a positive assurance of containing the developing fire with forces available. If there were no hope of immediate (16, 24 hour) suppression, then the campaign strategy for the situation would be effected, and regional resource allocations would be computer recommended after interrogation with the regional headquarters computer (Chapter IV).

During the suppression operations, the State of California headquarter's computer would keep track of all logistics expended and required in consonance with the predicted fire boundary spread computation and a recording of operational performance. It would also order out replenishments to the task forces, as their supplies reached predetermined low levels. In this regard, usage data would be reported by communications links from transmitters with the task forces. Water, petroleum fuel levels, foam, food, and other expendables would be continuously reported through communications links with geosynchronous orbit relay satellites, and kept track of. Resupply priority decisions could also be made from fire spread predictions to match logistic efforts to the highest operational needs.

The suppression effort is the summation of the task force efforts, and the management of these forces requires computer situational and prediction support. The California State Command Center would send each task force commander sufficient display data to help him control his operations in a real time sense. Fundamental operational units are shown in Figure 1.6. These command units would be mobile, and primarily not hard-wire linked to the California State Command Center. About 100 task force command vehicles would be involved for the State of California. Each task force commander would be given a specific task and geographical assignment by the California State Command Center. Primary air targets would be given by the CSCC to the air task force boss from the task force requests, and fire spread assessments made at the CSCC (Chapter VIII).

The task force commander would be obliged to pull out if so ordered by CSCC, but the on-scene deployment of his forces would essentially be his, and he would have scanning reconnaissance information of his force dispositions, plus the situation and prediction displays to guide him in his command decision-making.

The dispatch of the task forces and the release and roll up action would be much the same management process. The information system would reveal the success of the various parts of the suppression effort and recall and mop up would proceed without delay. Total unit expenditures of apparatus types and usage data would be in a history file that would be available for operational analysis, later or in real time if required.

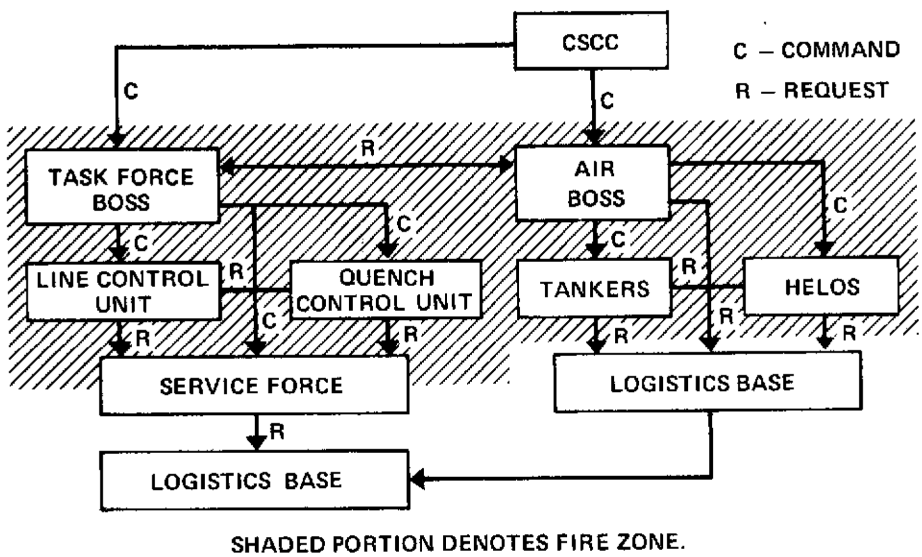

Figure 1.6 Fundamental Operational Units

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Chapter II

SATELLITE RECONNAISSANCE (STATE OF THE ART)

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Chapter II

SATELLITE RECONNAISSANCE

A. Introduction

Early in thinking about how the major efforts of system design should be divided, we agreed that consideration be given in turn to satellite reconnaissance, fire management (command and control), suppression operations and logistic support, system wide. This forms convenient costing categories; and the divisions are interrelated to the extent that a functional change in the features of one, reflect corresponding changes in the other. Satellites can provide accurate-pertinent data to support both active and passive fire-management programs.

Before we can cite the many references to support the use of satellites in data gathering, or proposed new uses, we must first establish fundamental physical concepts regarding satellite orbits and sensors. Several orbit configurations are to be considered; low altitude, medium altitude, a single synchronous orbit, or combinations of the above. Fundamental to the choice of orbits is the effect of the Van Allen Belt on satellite operational life; the resolution of the satellite based sensors; the ground track width of the sensor scan; the slope at which the ground is seen at the edge of the scan; and the time duration and frequency of coverage of any given spot on earth.

To establish these concepts and to review the application of the very-effective, recently-launched, Earth Resources Technology Satellite (ERTS) and the soon to be launched, Geostationary Operational Environmental Satellite (GOES), are discussed. (Nicholls, 1973; Vaeth, 1972; ERSS, 1971.)

B. Earth Resources Technology Satellite

1. ERTS Orbit

The ERTS illustrated in Fig. 2.1 was launched 23 July 1972 in a near polar orbit designed to photograph the entire earth once every 18 days. The satellite trajectory is a near circular orbit 9.114 degrees from the pole with a major axis of 7285.62 Km (4500 mi) approximately 892 Kilometers (555 miles) above the earth, and just below the Van Allen Radiation belts. In this orbit, it passes over the equator at 9:42 a.m. local time providing oblique lighting, optimal to the mineralogists, but far from optimal for vegetative sensing. This surveillance is said to be sun synchronous, providing the same illumination each time a given area is scanned. During one 18 day period, the satellite makes 251 revolutions around the earth, so that the ground path centers are 159.38 Km (100 n.mi.) apart.

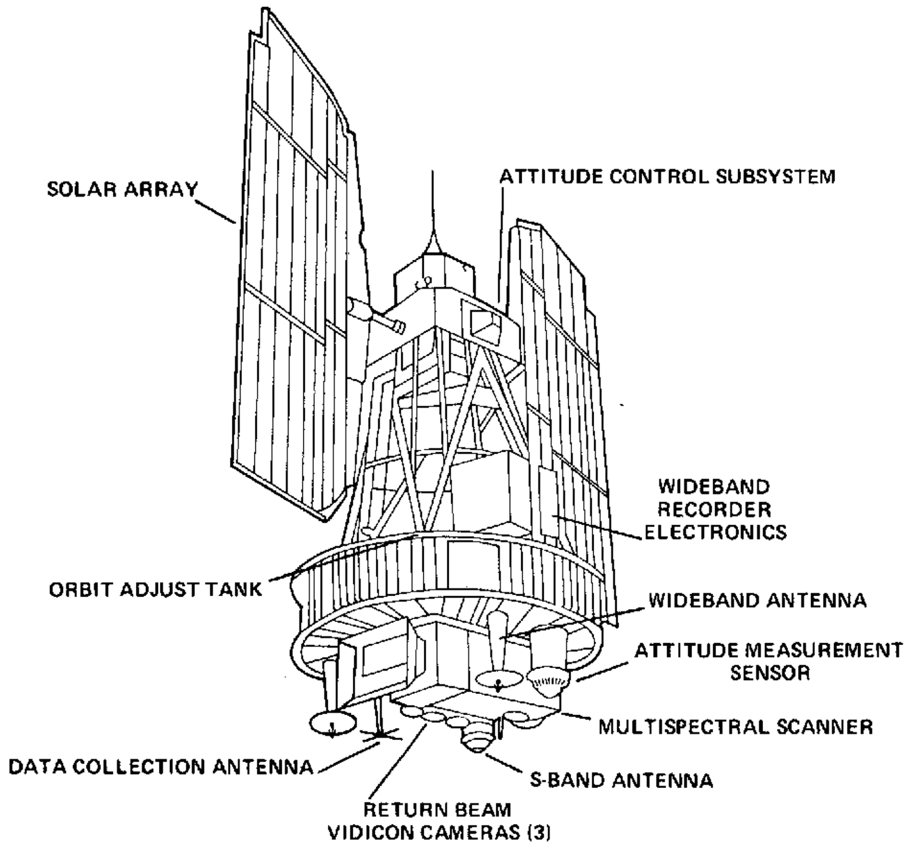

Figure 2.1 ERTS Spacecraft Observatory

2. ERTS Sensors

There are two types of sensors aboard ERTS; an assembly of 3 TV-like cameras, termed RBV or Return Vidicon types, to take high resolution pictures in 3 separate bands of the optical spectrum; and a multispectral scanner. The TV cameras each respond to one color. These are categorized into channels 1, 2, and 3 as follows:

Channel 1: Pass band: 0.47 - 0.57 μ M Blue-Green

Channel 2: Pass band: 0.58 - 0.68 μ M Green-Yellow

Channel 3: Pass band: 0.68 - 0.87 μ M Red-Infrared

The cameras are configured as in Fig. 2.2 and camera parameters are listed in Table 2.1. With the 160 kilometer $\times$ 160 kilometer (100 mi $\times$ 100 mi) area scanned by a 4125 line raster, each line width covers 38 m (125 feet). A sense of the resolution* of the cameras can be obtained by using the relationship $\theta_r = s/h$ (see Fig. 2.3) where "s" is the width of the scan line and "h" is the heighth of the satellite above the earth. In the case of ERTS the resolution,

$$\theta_r = 381892 \times 10^3 = 4.26 \times 10^{-5}$$

i.e., ERTS RBV resolution is approximately 4×10^{-5} radians.

The second sensing system aboard ERTS is a multispectral scanner (MSS) that gathers data by imaging the surface of the earth in several spectral bands simultaneously through the same optical system as depicted in Figs. 2.4. Scanning is achieved by the continuous $\pm 2.8°$ oscillation of a plane mirror which effectively scans across 158 kilometer (100 nautical miles) in a direction perpendicular to the motion of the spacecraft relative to the earth. That is, the mirror effects a scan in longitude and the motion of the spacecraft effects a continuous scan in latitude. A cassegrain telescope collects light from the oscillating mirror and focuses it onto a 6×4 element matrix of square section optic elements each of which subtends 79 meters square on the ground.

Based on the earlier definition of resolution the angular resolution of the multispectral scanner is $\theta_r = 7.7 \times 10^{-5}$ rad $\approx 8 \times 10^{-5}$ radians.

*This crude use of the word resolution, although improper in the eyes of the photographer and photogramitist, is effective here and is used throughout this report.

Table 2.1

RBV CAMERA PARAMETERS

Item	Camera 1	Camera 2	Camera 3
Nominal Spectral Band (micrometers)	0.475-0.575 Blue-Green	0.580-0.680 Green-Yellow	0.698-0.830 Red-IR
Abbreviated Band Reference	Blue	Yellow	Red
Edge Resolution (% of center)	80%	80%	80%
Video Bandwidth (MHz) without Aperture Correction	3.2(-20 dB)	3.2(-20 dB)	3.2(-20 dB)
Signal-to-Noise Ratio (at 100% highlight) Aperture Correction Out	33 dB	33 dB	31 dB
Horizontal Scan Rate (lines/second)	1250	1250	1250
Number of Scan Lines (active video)	4125	4125	4125
Readout Time (seconds of active video)	3.5	3.5	3.5
Readout Sequence	3	2	1
Focal Length of Lens (mm)	125.865	125.824	125.979
Exposure Set Time (msec)			
No. 1	4.0	4.8	6.4
No. 2	5.6	6.4	7.2
No. 3	8.0	8.8	8.8
No. 4	12.0	12.0	12.0
No. 5	16.0	16.0	16.0

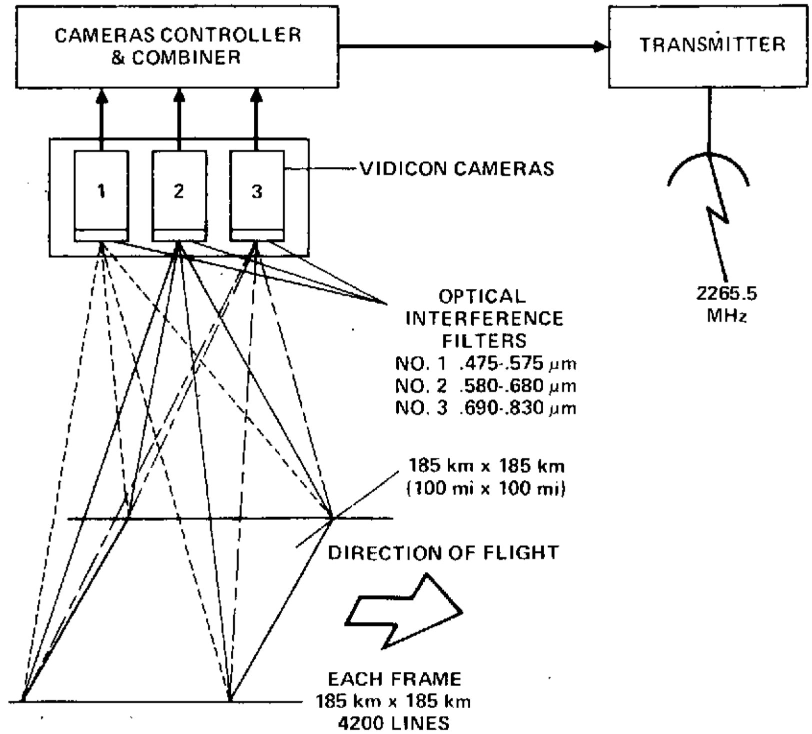

Figure 2.2 TV (RBV) Camera System

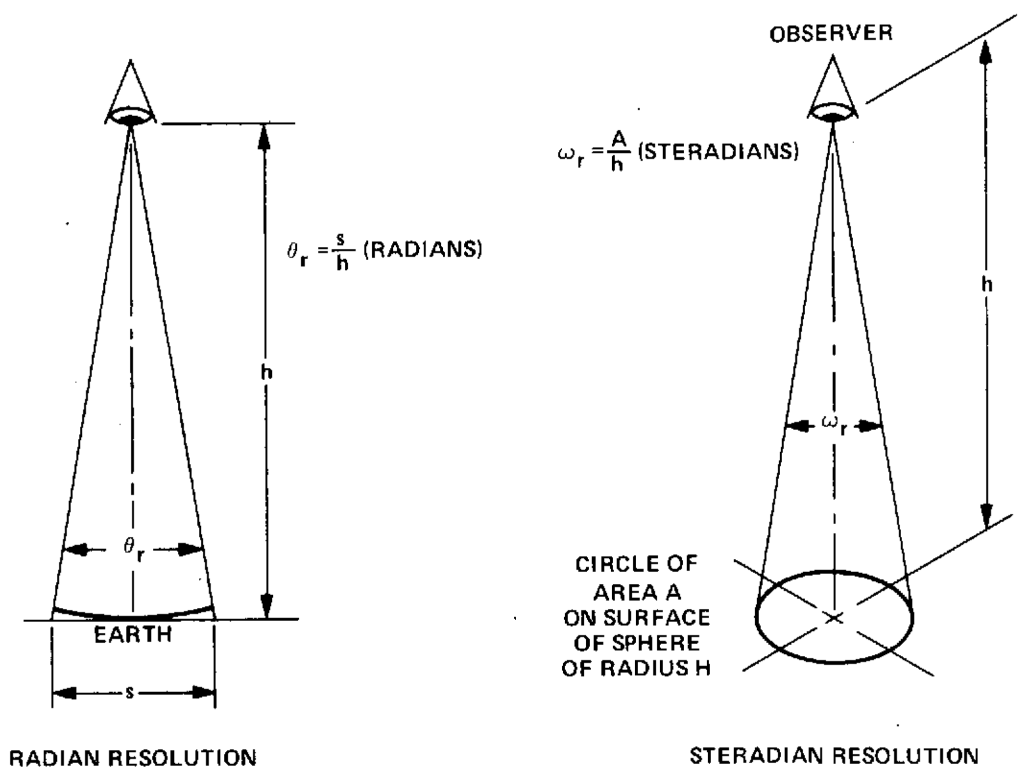

Figure 2.3 Radian and Steradian Resolutions

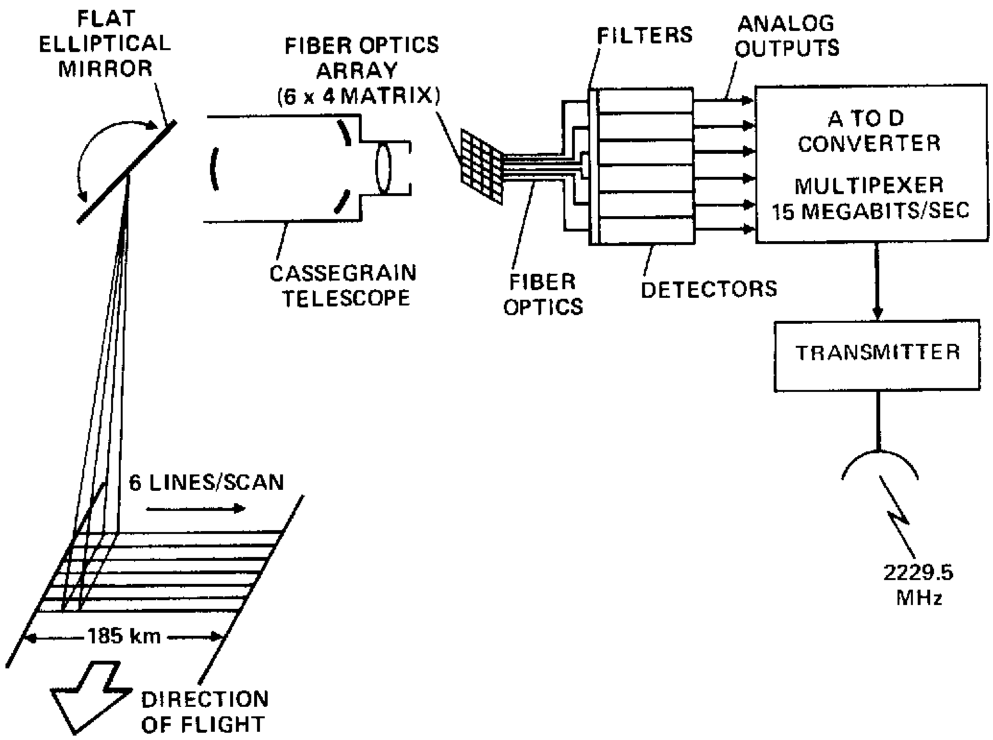

Figure 2.4 Multispectral Scanner

Six effective lines are scanned in each mirror movement and each of these lines is sensed by 4 filter detector combinations, one in each of the four bands as follows:*

Band 4: Pass band: 0.5 - 0.6 μm green

Band 5: Pass band: 0.6 - 0.7 μm yellow

Band 6: Pass band: 0.7 - 0.8 μm red

Band 7: Pass band: 0.8 - 1.1 μm infrared

(Bands 1, 2, and 3 designate the TV camera bands.) Bands 4, 5, and 6 are sensed by photomultiplier tubes. Band 7 is sensed by silicon photo diodes. In the upcoming ERTS B mission a Band 8 will be added for sensing in the thermal infrared: 10.4 - 12.6 μm. There are thus 24 separate detectors in the scanner, and the output from each is sequentially sampled and digitalized. As indicated above, cross (satellite) tracking is accomplished by rocking the 22.8 cm (9 inch) flat elliptical mirror at 13.5 Hz. The output from the MSS in digital form, is a single serial bit stream carrying an information rate of 15.06×10^6 bits per sec. In the ground data handling system (see Fig. 2.5), the continuous strip imagery of the MSS is transformed to framed images with about 10% overlap between consecutive frames, hence an average coverage of about 158 kilometers (100 nautical miles) square--about the same as the TV camera system.

3. ERTS Data Storage and Transmission

The TV cameras and multispectral scanner complement each other in several aspects. Both systems are operated simultaneously over the same path on the sunlit side of the earth. When operating within the range of a ground receiving station, the data are transmitted in real time to the ground site where they are recorded on magnetic tape. When not in the range of the receiver, the TV signal and multispectral scanner outputs are stored on satellite-based wideband-video recorders capable of 30 minutes storage each. When again in the range of a receiving site, a command sent from the ground can start transmission from either recorder. A breakdown in the TV system video recorder early in the ERTS mission has curtailed the TV operation, but the remaining multispectral scanner provides magnificent imagery. Figure 2.5 illustrates the communication channels to the spacecraft.

Once the video signal reaches the ground and associated storage, it is processed by NASA and made available to users at a nominal sum in the three forms as follows:

*Note in early data books these were labelled as bands 1-4 (MSS) respectively. To avoid confusion with similarly numbered bands of the RBV, they are now referred to as bands 4, 5, 6, 7.

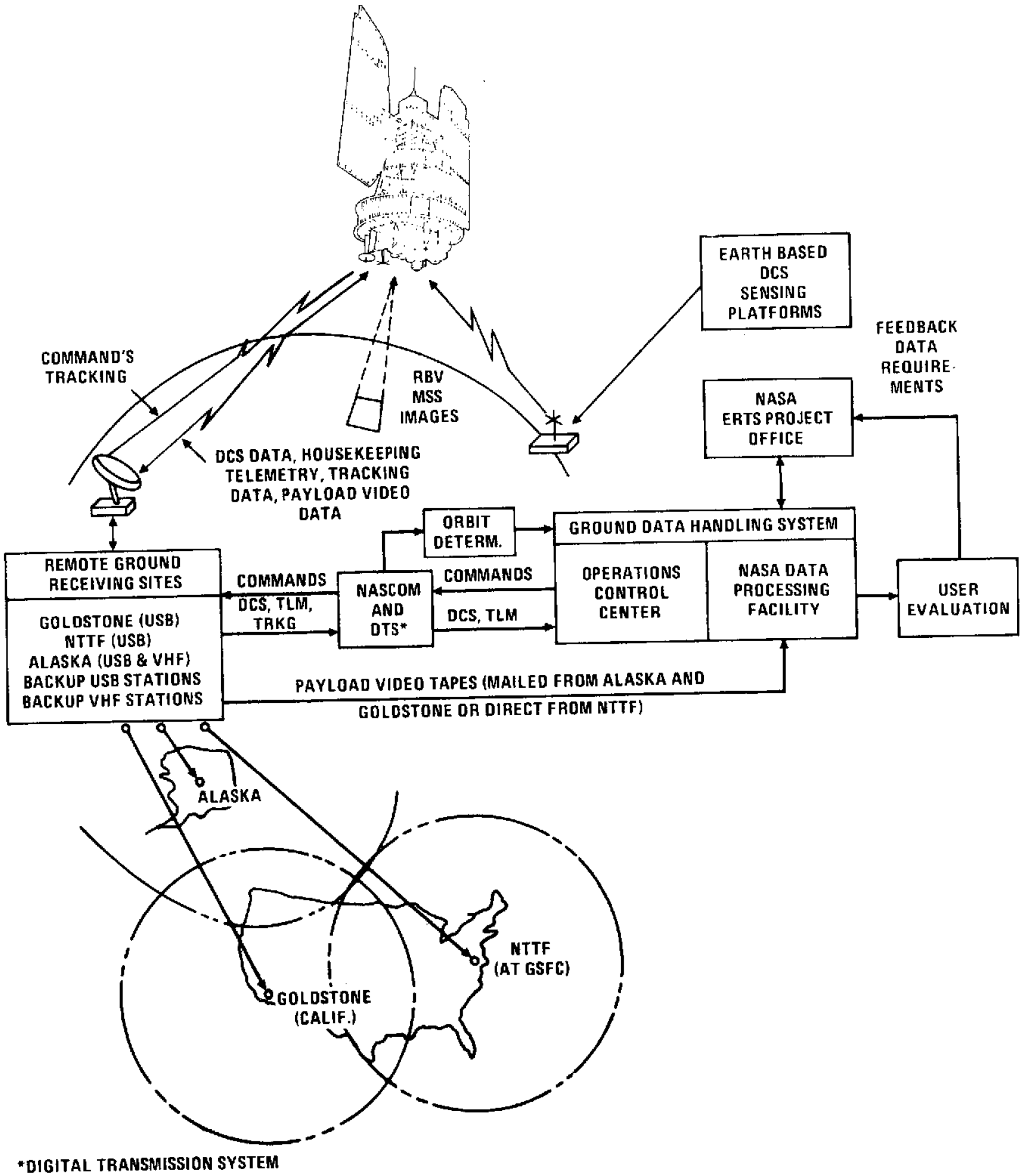

Figure 2.5 Overall ERTS System

(1) Black and white prints of about 100 nautical miles square in each of MSS bands 4, 5, 6, and 7.

(2) Color prints in each of the MSS bands and composite color prints of three superimposed bands.

(3) Digital tapes.

It must be recalled that the TV system is inoperative, otherwise the above list would be longer.

In order to depict the infrared of band 7 in color reproduction, false color techniques are used. Because the atmosphere is essentially opaque in the blues and ultraviolets, the color response of the film is shifted so that red photo images represent infrared objects, green represents red, and blue represents green. Most of the prints have identifying marks at latitude and longitude (in 30' arc) printed along each side. They also have crosses at 30' intervals across the body of the print, and a densimetric grey scale (indicative of the radiometric corrections which have been applied). The prints also have been corrected photogrammetrically for spacecraft motion. They are produced by modulated scanning electron beam devices which produce the master photograph material from which the prints are made.

Given the magnetic tape version of any of the 7 channels of data the user may apply pattern recognition techniques to selectively point out specific features of the photographs. This special data messaging is not generally provided by NASA.

The ERTS multispectral scanner in its one year of operation has provided vast amounts of data, of use to a broad range of users. Rather than go into the detail of each user's needs and results, the following table is provided (taken from Nicholls, 1973), indicating sensing strengths of the 4 MSS bands. It is noticed in Table 2.2 that as we go from the short wave length greens of MSS-4 through the longer wave length infrareds of MSS-7, we get decreasing water penetration, increasing cloud penetration, increasing discrimination between water and land, and decreasing sensitivity to turbidity and sediment load and phytoplankton density.

ERTS was put in orbit with an expected one year life. A minor malfunction results in limited use of the TV cameras, but the multispectral scanner is still operating very effectively after one year. However, due to the limited use of the TV cameras, users do not yet have a strong feel for the ultimate effectiveness of this subsystem. Plans for launch of the second ERTS satellite are being held up while the tremendous volume of data returned by ERTS A is sifted and analyzed to determine what possible changes might be desired in the new model.

C. Geostationary Operation Environmental Satellite

The soon to be launched GOES satellite (late 1973 or early 1974) will be placed in an earth synchronous orbit so that it remains 19,300 nautical miles (35,872 km) directly above the equator at 100° West

Table 2.2

SENSITIVITIES OF THE FOUR BANDS OF THE MULTISPECTRAL SCANNER

Band	Sensitivities
MSS 4 0.50 - 0.60 μm (G-Y)	- greatest water depth penetration (up to 70 ft or more) - most useful for studying intrinsic characteristics of water bodies - has optimum sensitivity to patterns of water pollution, water turbidity, phytoplankton density, submarine topography, atmospheric conditions - definition and discrimination of surface features hampered by atmospheric scattering (haze) - minimum cloud penetration - monitors maximum turbidity and sediment load - strong reflectance of dry and melting snow
MSS 5 0.60 - 0.70 μm (Y-R)	- suited to the identification of cultural features, urban and transportation infrastructures, logging roads, land use patterns, vegetation type and coverage
MSS 6 0.70 - 0.80 μm (R)	- water/land discrimination (can be fooled by shallow areas, or heavy sediment loads) - drainage networks, stream morphology - vegetation stress - bedrock structure - good cloud penetration
MSS 7 0.80 - 1.10 μm (IR)	- least water depth penetration - optimum water/land discrimination (infallible for mapping shorelines of oceans, lakes, wetlands) - vegetation stress - bedrock structure - drainage networks, stream morphology - has maximum cloud penetration - recent fire scars - strong reflectance of dry snow, reduced reflectance of melting snow (probably due to absorption by thin film of water)

longitude (that of central United States) thereby being able to effectively see the inhabited areas of North and South America except for Alaska and the Antarctic.

The prime environmental sensor on board will be the Visible Infrared Spin Scan Radiometer (VISSR). This will image the earth day and night. As implied by its name, the VISSR generates its scan by using the west to east spin of the spacecraft, sequentially "stepping" its scanning mirror north to south at the completion of each spin. To obtain a picture of the earth disk requires 1821 revolutions of the ship. At 100 RPM, each picture will require 18.2 minutes of sensing followed by 1.8 minutes of mirror retrace time followed by 3 to 5 minutes to damp retrace induced oscillation.

The VISSR telescope uses 20.5 cm (16 inch optics) with a 3.65 m (144 in.) focal length. Visible spectrum sensors will provide a 0.79 kilometer (0.5 nautical mile) resolution at the earth's surface while infrared sensors will have resolution in the range of 6 to 8 kilometers (4 to 5 miles). This corresponds to an angular resolution

$$\theta_r = 0.79/35,872 = 2.2 \times 10^{-5} \text{ rad}$$

These IR sensors will respond to the 180° to 315° K region with a sensitivity of about 1.4° K at 200° K and 0.4° K at 300° K.

The VISSR digitized output will be fed to Wallops Island, Virginia at rates up to 28 megabits per sec.

In order to handle the 28 megabit data rate at the 35,872 kilometer (19,300 n. mi.), distance of geosynchronous satellite operation, sophisticated ground stations are required. As an indication of the sophistication of the equipment involved, consider the fact that a 7.3 meter (24 ft) disk antenna is used for information interchange, and a laser beam sensitizing dry-silver film is used for imaging. Further, high-powered computers are located at the ground station which process the raw data and return it to the satellite for retransmission to the user.

1. GOES Transceiver Service

Both ERTS and GOES also collect transmitted data from ground-based environmental sensors and retransmit to remote sites. GOES will be capable of working with 10,000 such sensor platforms, handling 2 million bits of data in 6 hours.

2. GOES Resolution

The earlier mentioned high resolution (0.5 miles) is a goal of the development team not a guarantee, at least not on the first flight. For purposes of comparing this resolution with that of the ERTS sensors, recall that the angular resolution of the VISSR equals 0.79/35,872 = 0.22×10^{-4} radians. The coarse infrared sensor, with ground resolution of approximately 6.4 kilometers (4 miles), has angular resolution of only about 2×10^{-4} radians. Although the GOES visual spectrum sensors have better resolution than those of ERTS, the infrared sensors have effectively the same resolution. The term "resolution" must be used with great care as pointed out by Colvocoresses in his article on resolutions of ERTS, SKYLAB, and APOLLO (Colvocoresses, 1972). Attention is given to this matter later in this chapter as we speak of the expected performance of the sensor of 1990.

D. The Future of Sensor Resolution

There is much confusion concerning the resolution of IR scanners. In our work the ground resolution is taken as the widths of the ground seen in one scan line. The corresponding angular resolution θ_r is then given by the S/h where h is the altitude of the scanner above terrain and S is the scan width (see Fig. 2.5a). There are, however, cases of bright sources much smaller than one scan width which will supply sufficient energy to the sensor to cause the sensor to react as if a source were present, but the location of the source could not be specified to better than one scan width. If the energy reaching the detector is too low because the source is of low power, the lenses are too small, or the scan is too fast, then the source will not be detected. The ability to sense small high power sources is important but does not serve as a complete measure of resolution. It may not be able to differentiate between low contrast sources.

Hirsch et al (Hirsch, 1971; Wilson, 1971) analyzed development of a detection criteria based on spherical* trigonometry. Assuming background temperatures vary from 290°K to 310°K, the radiation differences at the surface is $W = 1.8$ watts/(cm^2 steradian °K). This 20° temperature change causes the radiation difference at the aperture of the scanner of the scanner of W_A (20°K) $= 2.4 \times 10^{-10}$ watts/cm^2 [assuming a spectral band pass of 3 to 6 microns, on atmospheric transmission of 50% and scanner resolution of 4×10^{-6} steradians (see Fig. 2.3b)]. The 700° fire target has radiant power W (fire) (between 3 and 6 microns with 50% attenuation) of 0.095 watts/(cm^2 steradian). The radiation from the flame that is available at the scanner is ω_fW (fire) where ω_f = the solid angle subtended by the fire target. Since the energy reaching the aperture generated by the flame must be greater than that change caused by background differences in order to be detected,

$$\omega_f W \text{ (fire)} > W_A \text{ (20°K)}$$

which implies

*Since most of the specification data considered in discussion between the author and IR experts has involved plane angles, plane trigonometry terminology will be used herein for final comparison. The concept of the solid angle ω is illustrated in Fig. 2.3b.

$$\omega_f = > \frac{W_A\ (20\,°K)}{W\ (fire)} = 2.5 \times 10^{-9} \text{ steradians}$$

for detection. Then where the scanner resolution

$$\omega_S = 4 \times 10^{-6} \text{ steradians}$$

$$\omega_f/\omega_S = (2.5 \times 10^{-9})/(4 \times 10^{-6}) = 6 \times 10^{-4}$$

Therefore, as shown in this simplified analysis, the fire will be detected in the sense that its signal exceeds the noise if it fills 6/10,000 of instantaneous field of view of the scanner. This example also indicates how many people confuse angular resolution with the IFOV (instantaneous field of view).

The National Forest Service System have used scanners with 1 to 4 milliradian ($\theta_r = 10^{-3}$ to 4×10^{-3} radians) angular resolution quite successfully from altitudes of the order of 6000 meters (20,000 feet), giving them a square IFOV of (20 to 80 feet), yet picking out (0s1 m^2) (1 square foot) fires. They do not know the location of the fire to better than 6 to 24 meters (20 to 80 feet). As pointed out earlier, however, the ERTS scanners have resolutions of the order of $\theta_r = 10^{-5}$ radians.

In attempting to learn the ultimate resolution of state-of-the-art IR scanners, we come up against the problem of military classification. Even the above cited work of the National Forest Service required lifting classifications. It seems reasonable to expect a resolution of the order of 10^{-6} to 10^{-7} for the period 1985 to 1995 for nonmilitary application. Such conjecture is supported by Angelo P. Margozzi of NASA Ames and Ralph W. Nicholls of York University, Toronto, Canada (Nicholls, 1973).

Use of such a high resolution scanner poses several obvious problems. In order for the longitudinal action to keep up with the motion of the supporting vehicle, tremendously high scan rates will be required, probably higher than mechanically feasible. Therefore, we will have to be looking at multispectral scans of the format of ERTS or infrared detectors built in the FLIR (Miller, 1973, 1,2) (Forward Looking Infrared) format. For the MSS a mechanical scan takes place providing, in effect, a multiple scan--one for each detector--each of which is addressed electronically during the scan, to produce a digital signal. This signal can be fed to a light emitting array which drives a vidicon, providing a continuous real time picture. In the case of FLIR system, the scan is carried out electrically. The corresponding video data can, of course, be recorded and processed as desired to enhance certain features as might be desired in locating a certain type of plant, or fire.

If we are operating with an angular resolution of the order of 10^{-2} to 10^{-3} times that of ERTS, we will be dividing the area covered 10^4 to 10^6 times more finely than ERTS. To maintain the quality of display for each area element, we will need 10^4 to 10^6 times as much data transmitted for a given area as ERTS. This will require special data processing and transmission techniques.

E. Possible Orbits

Now let's look at possible orbits for our satellites that are to serve as aid in wildland management. We will use sun synchronous orbits with all their inherent aids to photography. In order to be able to sense objects and vegetation on the ground of interest to wildland management, we require a ground resolution of the order of 3 meters. If we take note of the once-every-eighteen-day service of ERTS, we realize that either we need many satellites in the ERTS level, 728.5 km (altitude statute 550 mi) or a satellite(s) at higher altitude to get a wider look. The altitude of the orbit is highly constrained. For proper coverage, we need more altitude. We recall that ERTS (at 550 mi) orbits at the inside boundary of the high proton-density portion of the Van Allen belts. We cannot operate in the Van Allen belts because of the high density of high-energy protons. The electron portion of the Van Allen belts is of little concern because we can easily provide shielding against electrons but operation in the protons portion would destroy solar cells and would create considerable noise in, and tend to destroy, the extremely sensitive sensors.

Table 2.3 indicates the full range of sun synchronous satellites and the corresponding periods. Since the high-density of high-energy portion of the Van Allen belts runs from approximately 1000 to 10,000 kilometers (600 to 6,000 miles), most of these orbits cannot be considered. The first possibility outside the Van Allen belts is at 10,382 kilometers (6,460 miles). At this point, the concern for resolution becomes apparent. If we require a ground resolution of the order of 3 meters (10 ft), (10 ft IFOV) and we are orbiting at 10,382 kilometers (6,460 miles) then we require an angular resolution of

$$\theta_r = 10 \text{ ft}/(6080 \text{ ft/mi})(6450 \text{ mi}) = 0.254 \times 10^{-6} \text{ radians}$$

It is noted that this is the order of the anticipated angular resolution of the 1990 sensors, therefore, we cannot operate any higher. From the above, it is seen that we must operate either at the ERTS altitude or at 10,382 kilometers (6,460 miles).

F. The Availability of Satellite Vehicles in the 1990's

Admitting that we cannot expect wildland agency funding of any more than a small portion of the total cost of the required satellite system, we must establish outside support for a "high powered" resources satellite system that will be of use to the wildland agencies.

It is recognized that such a satellite system cannot fully respond to California Wildfire needs, but it provides worldwide coverage and therefore a potential firefighting capability to any nation who wants to share a burden of the system costs. For example, Canada and Australia

Table 2.3

SUN SYNCHRONOUS CIRCULAR ORBITS

	Number of Orbits/Day	Period Hour	Altitude	
			km	miles
SMS/GOES	1	24	35,872	22,260
	2	12	20,132	12,470
	3	8	13,932	8,670
	4	6	10,382	6,460
	5	4.8	8,072	5,040
	6	4	6,522	4,050
	7	3.43	5,167	3,142
	8	3	4,182	2,606
	9	2.67	3,392	2,100
	10	2.4	2,722	1,700
	11	2.18	2,157	1,340
	12	2	1,682	1,045
	13	1.845	1,262	785
ERTS	14	1.714	892	555
	15	1.6	567	347
	16	1.5	277	172
	17	1.41	7	
	18	1.333	-228	

could just as well benefit in updating their fire fighting potential as the whole U.S.A. or California as a particular state.

Similarly, the sharing of all nations in the benefits of search and rescue, micro weather warning, and pollution control as well as longer range earth resource analysis could be achieved. This places such a system on a potential peaceful consortium basis and puts the U.S.A. in the position of having something to sell in an international market. Thus, there are other strong justifications for a worldwide reconnaissance capability.

This satellite system concept has justification in the present ERTS-A and soon to fly ERTS-B system. "Earth Resources Survey Program" (ERSP) is shared by 25 countries who submitted 60 proposals for the use of the raw data from the sensors. These countries are:

Argentina	Chile	Guatamala	Netherlands
Australia	Columbia	India	Norway
Belgium	Ecuador	Indonesia	Peru
Bolivia	France	Israel	Sweden
Brazil	Germany	Japan	United Kingdom
Canada	Greece	Korea	Venezuela

The effectiveness of the present ERTS is evidenced in the 1227 page works (SOS ERTS, 1973) assembled for the March 1973 Symposium on ERTS results. In Table 2.4 is a list of the needs of the wildland management agencies, each of which is addressed in the just mentioned works.

As an indication of extensive use of multispectral scanning, like that of ERTS, consider the multispectral scanning efforts of a broad range of investigators presented in Table 2.5 (Nicholls, 1973).

Based on the listed needs of the wildland agencies, and looking at the range of efforts in multispectral scanning, we expect to find a satellite-data-gathering system operating in the 1990's on which we can hitch a piggyback ride. Better yet, if we have the foresight to perceive this opportunity of the future, we can, by early efforts, help to configure the system optimally for wildland fire needs.

Yet a further indication that an environmental satellite system for the future is a valid national planning objective, one should look at the report by Van Vleck et al, titled, "Earth Resources Ground Data Handling System for the 1980's" (Van Vleck, 1973). We did not become aware of this report until late in our preparation, yet there is much consistency in the separate efforts regarding system configuration, sensing devices and methods, and data transmission and processing.

The ERTS type satellite system has been shown to be economically effective in the analysis and generation of large amounts of data. (ERSS). Therefore, we believe that in 1985+ this satellite system should be incorporated into wildland management and fire control. This becomes then a part of the assumption rationale for the study, i.e., the satellite costs do not require a complete funding from wildland management efforts alone.

Table 2.4*

INFORMATION NEEDS OF THE ENVIRONMENTALIST

A. Land Information Needs

1. Landform classifications
2. Land use information
3. Geologic structural information
4. Subaqueous landforms

B. Water Information Needs

1. Relative soil moisture
2. Suspended sediment distribution
3. Wetlands distribution
4. Surface water and snow distribution

C. Vegetation Information Needs

1. Natural vegetation distribution
2. Agricultural vegetation distribution
3. Vegetation quality

D. Cultural Needs

1. Urban planning
2. Rural planning
3. Pollution distribution

*The "information needs identification" for the justification of the ERTS are presented in the following table taken from Earth Resources Survey System (ERSS, 1971).

Table 2.5

BASIC AND APPLIED DATA SOUGHT THROUGH MULTISPECTRAL REMOTE SENSING BY WORKERS IN VARIOUS DISCIPLINES

I. FORESTERS AND AGRICULTURISTS

A. Basic

1. Amount and distribution of the "biomass"
2. Nature and extent of important "eco-systems"
3. Amount and nature of energy exchange phenomena

B. Applied

1. The species composition of vegetation in each area studied
2. Vigor of the vegetation
3. Where vegetation lacks vigor, the causal agent
4. Probable yield per unit area and total yield in each vegetation type and vigor class
5. Information similar to the above for livestock, wildlife, and fish
6. Location of incipient forest fires

II. GEOLOGISTS

A. Basic

1. Worldwide distribution of geomorphic features
2. Energy exchanges associated with earthquakes and volcanic eruptions

B. Applied

1. Location of certain or probable mineral deposits
2. Location of certain or probable petroleum deposits
3. Location of areas in which mineral and petroleum deposits of economic importance probably are lacking

III. OCEANOGRAPHERS

A. Basic

1. Diurnal and seasonal variations in sea surface temperatures and subsurface temperatures

Table 2.5

CONTINUED

2. Vertical and horizontal movements of ocean currents and individual waves

3. Global, regional, and subregional shoreline characteristics and the changes in these characteristics with time

4. Diurnal and seasonal movements of fish, algae, and other marine organisms

B. Applied

1. The exact location, at a given time, of ships, icebergs, storms, schools of fish, and concentrations of kelp

2. The location of ocean beaches suitable for recreational development

3. The rate of spread of water-pollutants and the kind and severity of damage caused by them

IV. METEOROLOGISTS

A. Basic

1. Diurnal and seasonal variations in cloud cover, wind velocity, and air temperature, and humidity in relation to topography and geographic locality

2. Accurate statistical data on the points of origin of storms, the paths followed by the; their intensities, and their periods of duration

B. Applied

1. Early warning that a specific storm is developing

2. Accurate tracking of the storm's course

3. Accurate periodic data on air temperatures, humidity, and wind velocity

4. Accurate quantitative data on the response of the atmosphere to weather-modification efforts

V. HYDROLOGISTS

A. Basic

1. Quantitative data on factors involved in the hydrologic cycle (vegetation, snow cover, evaporation, transpiration, and energy balance)

Table 2.5

CONTINUED

2. Quantitative data on factors governing climate (weather patterns, diurnal and seasonal cycles in weather-related phenomenal)

B. Applied

1. The location of developable aquifiers
2. The location of suitable sites for impounding water
3. The location of suitable routes for water transport
4. The moisture content of soil and vegetation

VI. GEOGRAPHERS

A. Basic

1. Global, regional, and subregional land use patterns
2. The nature and extent of changes in vegetation, animal populations, weather, and human settlement throughout the world

B. Applied

1. The exact location, at any given time, of facilities for transportation and communication
2. The interplay of climate, topography, vegetation, animal life, and human inhabitants in specific areas
3. The levels of economic activity and the purchasing habits of inhabitants in specific areas

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Chapter III

SATELLITE SYSTEMS APPLIED TO WILDLAND FIRE CONTROL

LIST OF FIGURES

Chapter III

SATELLITE SYSTEMS APPLIED TO WILDLAND FIRE CONTROL

A. System Rational for Fire Control

The general question posed in this section is "What can be done in the 1985-1995 time period to deal with California's wildland fire problem as compared to what is being done now?" This question in practice reduces to "What can a satellite system do in the projected state of the art for the 1985-1995 time period to deal with the California Wildland fire control problem?" In this vein, the flow charts (Figs. 3.1 and 3.2) indicate where the satellite can contribute to both a passive prevention capability as well as an active suppression role.

1. Wildfire Prevention

If the primary prevention services are considered in Fig. 3.1, the satellite can generate quantitative information regarding:

(a) People Management: What wildland areas are being used by how many people and what is the nature of their use; what the configurations of the structures are, and the baseline data for generating management statistics.

(b) Land Management: Since it is feasible to distinguish roofing materials on structures and the impingement of potentially dangerous vegetation around structures, it can aid in the inspection or survey procedures that implement fair insurance rate appraisals and zoning ordinance enforcement policies regarding fire hazards. The data necessary for the calculation of the fire danger rating (FDR) figure for a specific area can be automated. These considerations amplify the need to inspect and observe the conservation measures undertaken to prevent the outbreak of wildfires.

(c) Fuel Management: Detailed information regarding the nature, type, and distribution of wildland vegetation (fire fuel) can be determined. The geography and efficiency of existing fuel breaks can be continually updated. The data needed for planning land management programs regarding wildfire, e.g., fuel break clearance, burn outs, water cache supply placement can be ascertained. Management decisions for prevention burning, e.g., prescribed burns, slash removal, or "let burn" action can be implemented with the assurance of a high probability of success.

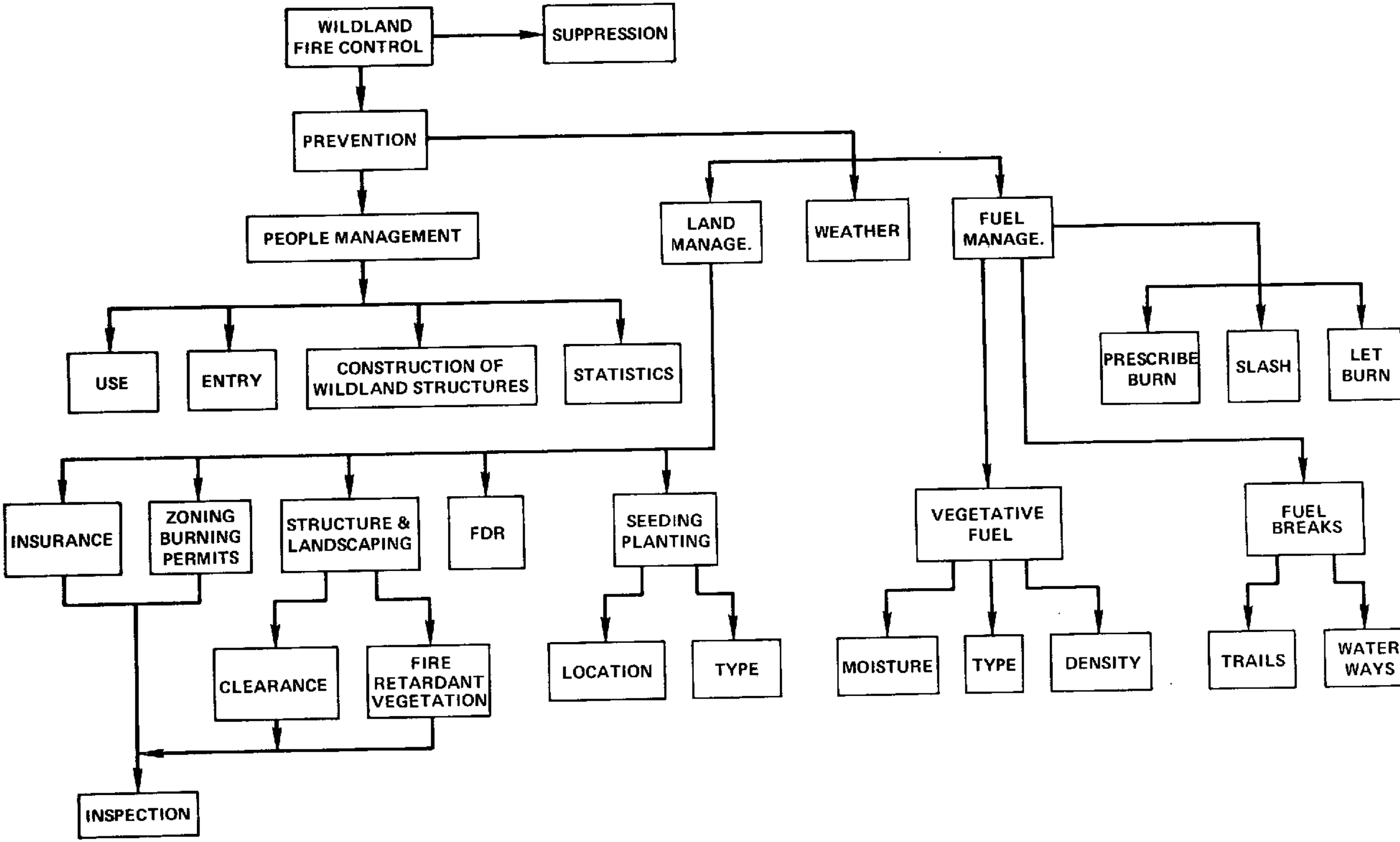

Figure 3.1 Satellite Sensing Requirements: Passive Prevention

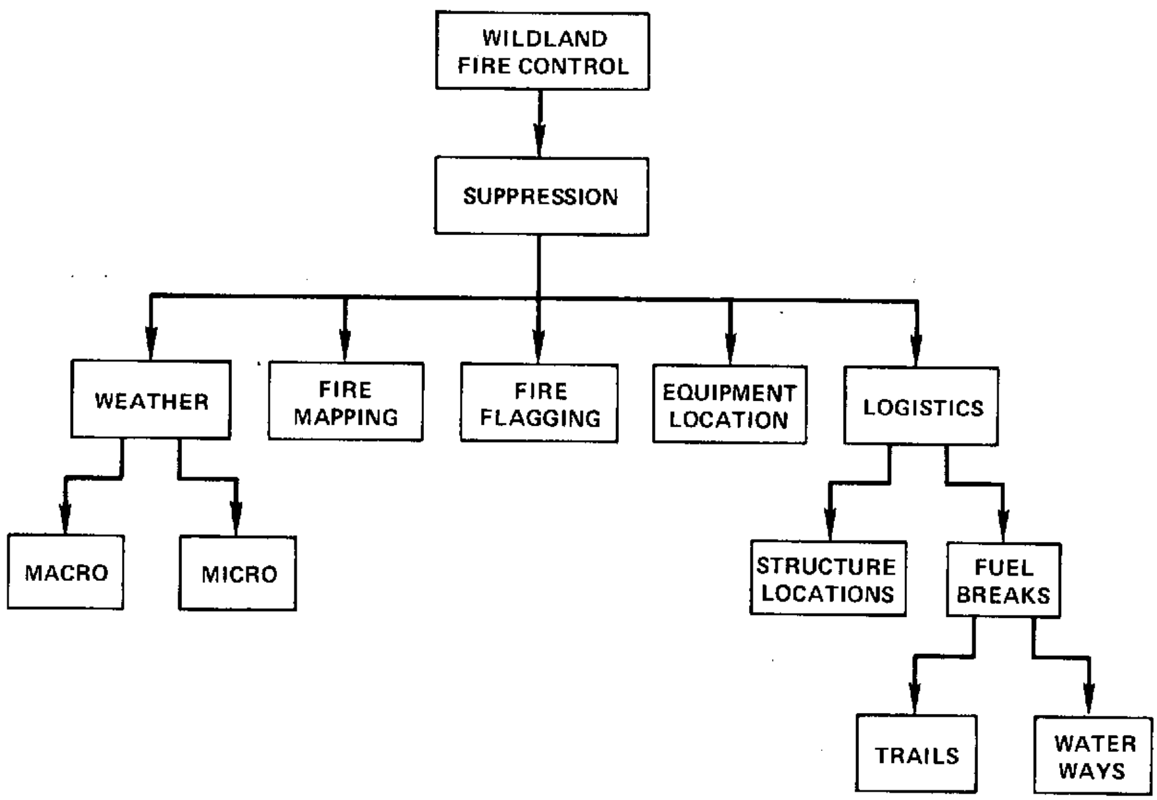

Figure 3.2 Satellite Sensing Requirements: Active Suppression

(d) Weather: The satellite cannot manage the weather directly, but it provides a factual source for detailed information regarding local weather conditions that have many important passive as well as active wildfire ramifications. In general, the gathering of information by a satellite, establishes a data base from which a wildland management system can be anchored to tie its decisions rationally and scientifically toward fire prevention.

2. Wildfire Control

The role of a satellite system in wildland fire suppression, i.e., its real time use in putting out fires has its major dependence on two factors.

(1) What is the satellite passover schedule?

(2) What is the response time, i.e., how fast can the fire data be detected, processed, and transmitted to the appropriate ground stations?

B. Satellite Passover Schedules and Fire Suppression

Since the wildland fire control data gathering system has a rather low priority as compared to other potential uses of the satellite system, e.g., urban planning, crop estimates, etc., its coverage schedule is essentially determined by the minimum time needed to implememt more important survey problems. Such areas as pollution control, oceanographic tracking, and flood control would set the minimum coverage time. It was under the constraints of these problem areas rather than the wildland fire control system that determined the estimate of a minimum one hour coverage schedule for the general satellite system. Taking this line of reasoning one more step precludes that the cost effectiveness of an instantaneous coverage satellite system specifically designed for wildland fire control suppression is justified.

1. Suppression Data Requirements

On the basis of this reasoning and on review of material in Chapter I, the satellite system chosen for study is assumed to be "general purpose" with a 20 minute lifetime over California every hour. This is more than adequate for a prevention role, but it limits the supression role to a one hour check on:

(a) Weather: The macro and micro weather situation can be updated for any burning or threatened area for use in predicting fire boundary spread through computer modeling.

(b) Fire Mapping: Accurate pictures of fire boundaries and spot fires, are available day and night every hour.

(c) Fire Flagging: Since there is a one hour delay this aspect of satellite use is severely limited except in certain relevant situations such as lighting induced fires and number of campfires.

(d) Equipment Location: The satellite can receive and transmit special data that can be used to update vehicle locations and logistic status at a local fire.

(e) Fuel Breaks: The computer support elememt of the system will have data banks incorporating the location and/or efficiency of fuel breaks for containment of ongoing fires.

2. Communication Time

Fire suppression capability and satellite coverage schedule are integrally related to the communication system. As indicated, another factor relating to the suppression ability of the satellite system is the response time--how fast can data be delivered to the fire fighting management. The general constraints of the overall system design puts the entire suppression contribution on a quasi real time basis. The scanning response time is determined by several factors:

(a) sweep time of sensors

(b) data storage and processing

(c) bit rate

These factors plus others accumulate to give a scanning response time more than that determined just by the satellite coverage schedule alone.

3. Problem Areas

Reviewing the rational for the system design yields several major problems that need special attention:

(a) What parameters must be measured by the satellite system?

(b) How will the parameters be measured?

(c) What kinds of sensors are needed?

(d) What kind of communication system is required?

These questions are answered throughout the rest of this chapter.

C. Wildland Fire Control Sensing Needs

The design of the wildland fire control system is ultimately based on the particular earth surface parameters which can be remotely sensed by the satellite system. Classifying the various decisions that must be made in a fire management scheme essentially directs what features and parameters must be available in the fire management data bank. Figure 3.3 breaks down the sensing needs to "real" quantities which must be measured or located. This figure is used as a starting point in that it defines what specific items must be included in the fire management data bank. The use of these items in implementing fire mangement doctrine is assumed to be a priori information at this point.

The next question which remains to be answered is how these items are detected by the remote sensing appartus, though it must be kept in mind that the satellite sensors are not designed specifically for wildland management decisions because of the higher priorities of other system users. Using this "piggyback philosophy," the following discussion is directed to how the sensing needs depicted in Fig. 3.3 can be derived even though the satellite sensing apparatus is not specifically geared to wildland fire control.

D. Technological Considerations of Sensing

1. Measurement Objectives

The definition of remote sensing is to derive information by measuring the spectral, spatial, and temporal variations of electromagnetic emissions from specific points of interest on the earth's surface or vicinity. The recorded information of a sensor depends upon:

(a) spectrum of the illuminating source

(b) atmospheric effects

(c) reflection characteristics of points of interest

(d) sensor properties

These characteristics are highly interdependent in a sensing system and very complicated in nature. It is not the purpose here to pursue a highly technical discussion, therefore references are given in the bibliography (optics and electromagnetic theory (Stone, 1963), Spectroscopy (Hertzberg, 1944, 1950, 1955), Black Body Radiation (Richtmeyer and Kennard, 1932), Atmosphere Absorption (Goody, 1964), Reflectance of Surfaces (Born and Wolfe, 1968).

2. Methodology

Remote sensing technology can be divided into two general methodologies:

(a) passive sensing

(b) active sensing

Only inherent radiations (usually reflected sunlight or thermal radiative effects) from a target are detected in passive sensing, i.e., there is no control over the source that may be illuminating a target. In active sensing, a specific emission is directed to the target and only scattered radiatión from this particular source is detected at the sensor platform. Active sensing has an advantage compared to passive sensing because specific target characteristics may be interrogated by designing the illumination source (usually in the microwave band) to have certain properties. The diadvantage of active sensing is that the payload of the sensor platform may be reduced because of the need for generating an illuminating source.

3. Spectral Widths

The electromagnetic radiation spectrum that is commonly used for sensing, lies in the range from approximately 1 GHz to 10^6 GHz or from microwave to ultraviolet. Only certain regions within this band are useful for sensing because of atmospheric absorption effects. As indicated in the previous chapter, the ERTS satellite sensors lie in the optical range (0.75×10^6 GHz to 0.4×10^6 GHz) and near infrared range (0.4×10^6 GHz to 10^4 GHz). Sensor operating in the far infrared and microwaves have been examined with aerial techniques. (Earth Resources Survey Systems (ERSS), 1971.)

4. Image Enhancement

Important as the sensors are in deriving recorded information, there are a varying number of enhancement techniques that may be applied to this information to amplify its usefulness. These enhancement techniques are what currently make remote sensing an art rather than a science. The ground truth of the sensing data must first be generated, then specific techniques (algorithms) to highlight desired characteristics are applied via computer processing and/or photographic manipulation. Reviewing the literature in this field, will show the great amount of explorations that have been applied via enhancement techniques to recorded sensor data (AIAA Earth Resources Observations and Information System Meeting (EROIS, 1970).

5. Vegetation

Sensing vegetation is an important area where enhancement techniques have been applied to a considerable extent; thus this topic can serve as a useful example to indicate the integration of recorded information and post processing (Fig. 3.4).

Due to the seasonal changes in vegetative growth features, it has been verified that multidate imagery in various spectral band may be more useful in differentiating forestry plant types than multiband imagery taken at a single date (ERSS, Colwell, 1971). Colwell's result was found after extensive work was performed in verifying the ground truth of imagery. The botanical features of the target coupled with ground surveys directs the manner in which sensor inputs are accumulated. After imagery is acquired, numerical as well as photographic means have been established to further differentiate plant species. A numerically orientated enhancement system philosophically is geared more to computer processing; therefore it will be pursued further.

6. Data Processing

Numerically processing sensor data is tied directly to forming a two or more dimensional spectral space. Considering an elemental area on the earth's surface, radiations from a multitude of spectral bands may be detected. Recordings of this nature define the elemental areas spectral signature. Since different vegetative types have different spectral features, a priori knowledge can be programmed into the processing system. In practice, the spectral signatures of each plant type will overlap in forestry applications and other techniques must be applied. The next step is to form a "feature space" (ERSS, Landgrebe, 1971) where the spectral response of one band is plotted against the spectral response of another band for each elemental area. With ground truth verifications, contours can be plotted in the artificially produced feature space that can differentiate between plant species in each elemental area.

7. Recognition Algorithms

To be practical, efficient algorithms must be programmed in the computer processing to accomplish this. The application of computer algorithms to feature space presentations is the most important numerical enhancement technique which may be applied to vegetative sensing alone; there is no reason why this technique cannot be implemented to verify ground truth in other areas, structural roofing for example. Futuristically speaking, enhancement techniques are assumed to be available in the 1985-1995 time period for all sensing areas depicted in Fig. 3.3.

Satellites have just begun to demonstrate the possiblities for wildland fire control. Current sensing techniques serve as a genesis for detecting sensing parameters (delineated in Fig. 3.3) necessary for the proposed wildland fire control management system.

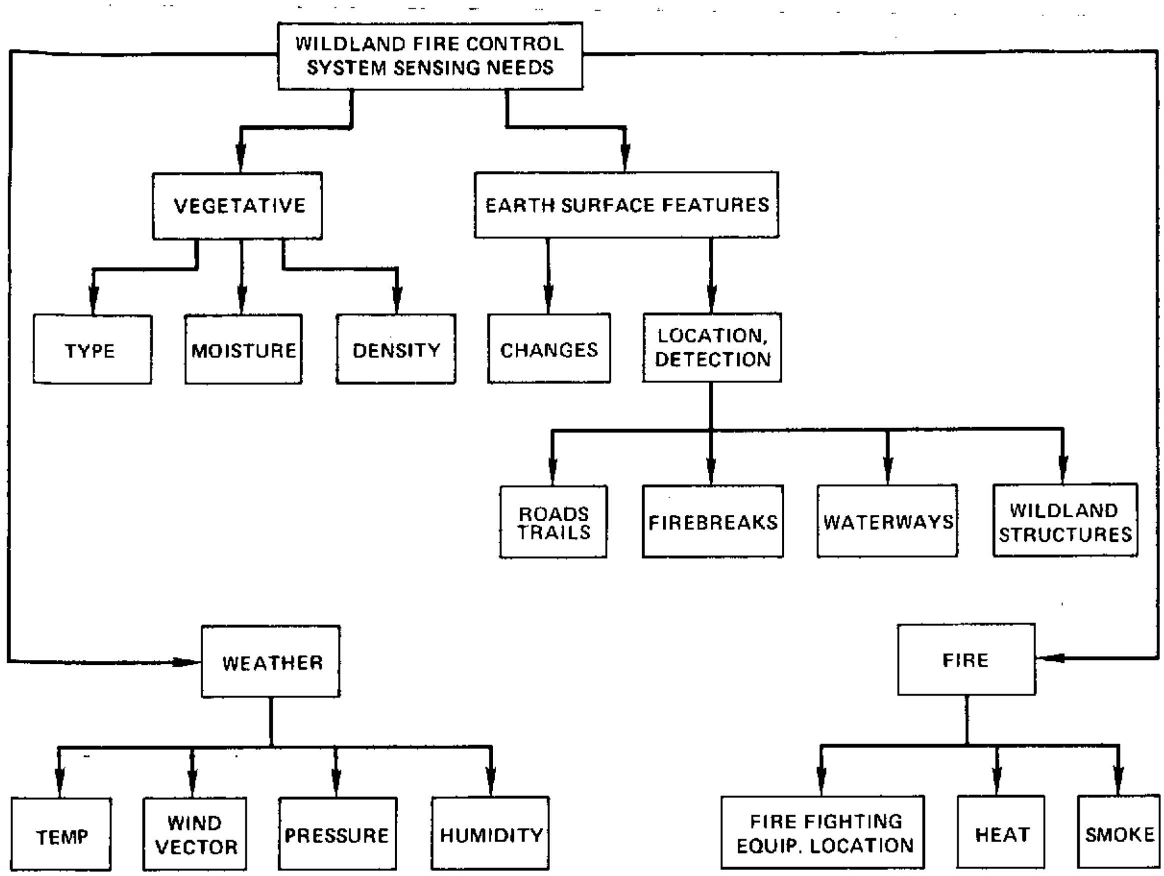

Figure 3.3 Wildland Fire Control System Sensing Needs

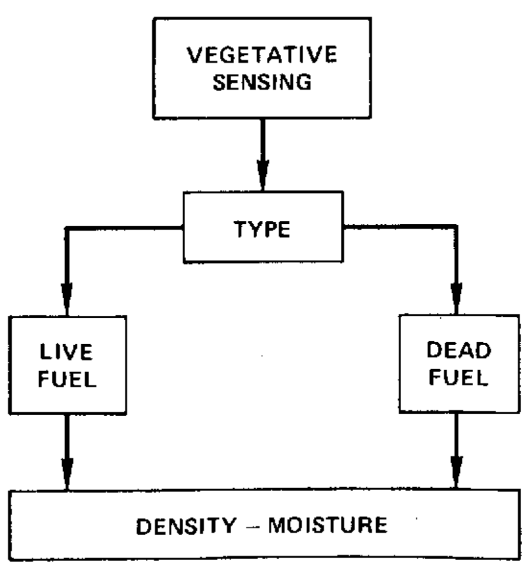

Figure 3.4 Vegetative Sensing

E. Vegetative Sensing

This aspect of sensing is most difficult to address because of the multitude of different plant types and their random distribution in the California wildland areas. The data bank in the wildland management system must keep a geographical inventory of plant types, live and dead fuel densities, and moisture to be effective in both the prevention and suppression missions. Using Fig. 3.4, the various steps are shown which are necessary to implement the vegetative parameter survey. First, the specie type must be established, then a determination of live and dead fuels for each plant type must be obtained, and last the fuel moisture must be determined.

F. Specie Identification

1. Resolution Required

It has been verified that the resolution required to distinguish general wildland vegetation brush, grass, and forest can be on the order of 100-150 meters (ERSS, Colwell, 1971). In fact, Colwell suggests that for the delineation of forested, brush-covered, or grass-covered areas, this resolution is quite adequate. For the determination of specie type within these categories, finer resolutions must be used in conjunction with multidate spectral enhancement techniques.

2. Spectral Combinations

Distinguishing vegetation by using combinations of spectral readings has been successfully performed (ERSS, Moore, 1971). Moore cites photographic imagery in conjunction with radar imagery to differentiate sugar beet crops. For example, sugar beets have a high dielectric constant but, otherwise have essentially the same reflectance properties as other plants. By comparing reflectance type photography and radar imagery, sugar beet crop areas can be readily separated from all others.

3. Pattern Difference

Another approach in distinguishing vegetation is to use the differences in growth patterns during a season. This technique has been exploited, through the use of multidate imagery readings for resolutions consistent with the homogeneity of the plant type (ERSS, Colwell, 1971). Thus the temporal differences in vegetation types are more diagnostic than spectral differences in some cases.

4. Possible Techniques

The staggering amount of possibilities used in plant specie identification, for example:

(a) multidate imagery

(b) multispectral imagery

(c) photographic and numerical enhancement

(d) terrain influences

(e) botanical differences

demonstrate that vegetative remote sensing is an ongoing technology, and resolutions on the order of 3-4 meters will enable, at the very least, average inventories of plant varieties to be made in the wildlands. The algorithms to differentiate these species are still under development and depend upon the permutations of the data collected as indicated above.

G. Fuel Density and Moisture

1. Vigor

Figure 3.4 indicates, that once specie type distribution is determined, an identification of live and dead fuel levels must be made. A remote sensing signal capable of tree top penetration must be used to determine ground fuel densities. This requires that only the long wavelengths (1 meter) be used. In addition, using the 1 meter microwave band only guarantees that penetration will take place when viewing directly overhead. This condition puts too much of a constraint on the satellite orientation, and once more there is a strong reason against the use of active microwave sensing in the system.

2. Live/Dead Fuel Ratios

In thickly forested lands where tree-top cover is dense, remote satellite sensing of ground fuel densities are exluded, and the burden of identifying ground fuel densities depends on ground surveys. For relatively open forested areas, the techniques of vegetative remote sensing may be used to obtain fuel densities. This implies that specialized algorithms be developed to determine the average live to dead fuel ratios.

3. Vigor Update

Once an initial starting point is reached in determining fuel densities by either remote sensing or ground survey in dense regions, the update of these statistics is relatively easy, because plant vigor can be sensed quite easily (Earth Resources Aircraft Program Status Review (ERAP), Allen, 1968; ERSS, Colwell). Sensing plant vigor is either associated with the loss of water accumulation or the change or degradation in chlorophyll content. Plant vigor is sensed by the highly dependent reflectance property of near infrared radiation on the moisture content of vegetative structure and by the change of plant color in the optical region when chlorophyll content is changed. The reflectance change in the infrared manifests itself before the chlorophyll changes, and explains why plant vigor loss can be seen more readily on infrared imagery than by an expert on the ground walking through a field (ERSS, Colwell, 1971).

4. New Growth

Plant vigor thus indicates the amount of live fuel that may be changed into dead fuel, but it does not indicate the change of live fuel density due to new growth. This update is relatively easy to implement because multidate imagery (a necessity in vegetative sensing) can be compared, such that long time base changes can be forecasted using a priori botanical principles.

5. Vegetative Sensing

Figure 3.5 reviews the techniques put forth in this section, and indicates the interweaving of the various steps applied in the total vegetative sensing process. An example of a typical densely forested area would proceed as follows:

(a) Obtain imagery (100-150 meter resolution) and define boundaries of grass, brush, forests.

(b) Obtain imagery (3-4 meters resolution) and define densely forested regions. Note grass and brush areas have relatively little top cover, and would be adequately surveyed and defined at this point.

(c) Determine fuel types that are live and their densities.

(d) Send survey teams to densely covered areas to obtain live and dead ground fuel densities at representative locations.

(e) Correlate imagery with survey results.

(At this point live and dead fuel densities both at the ground and top cover are known; thus the remaining steps need only determine the moisture and fuel density change.)

(f) Correlate top cover moisture with plant vigor sensing data.

(g) Use remote transmitting stations to determine live and dead fuel moistures. (More will be said about these remote stations in the section on weather sensing.)

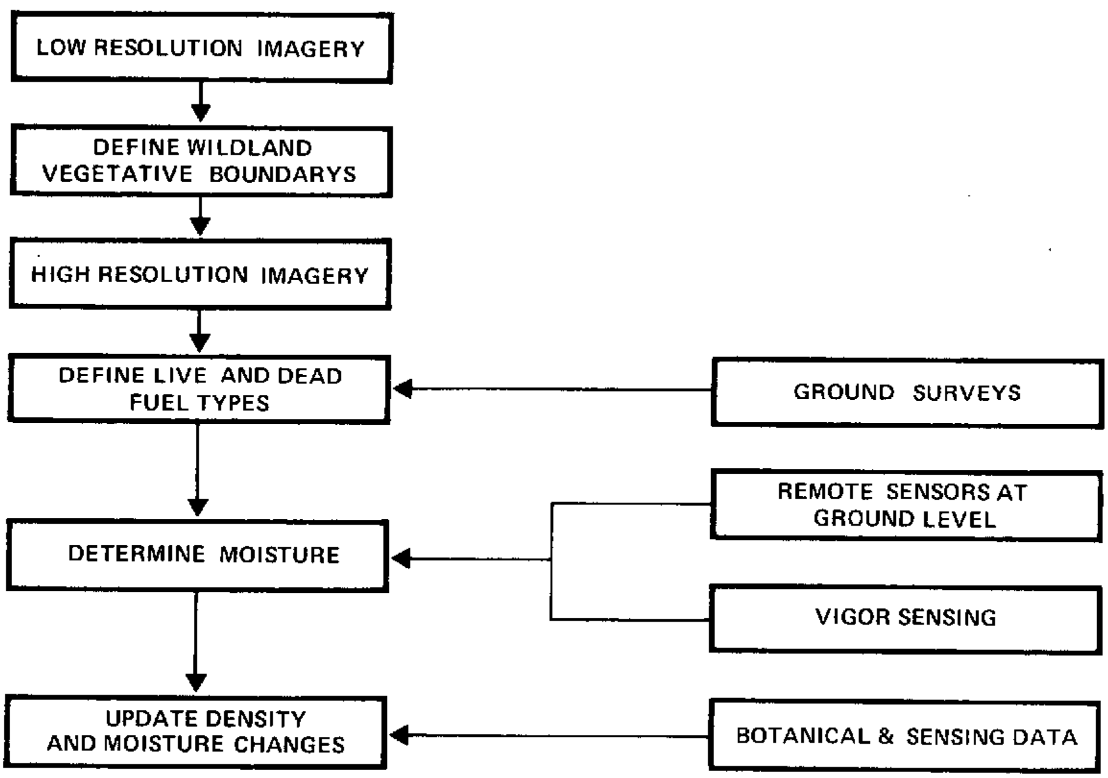

Figure 3.5 Steps Needed to Implement Vegetative Sensing

(h) Correlate both vigor sensing and botanical information to determine live and dead fuel density changes.

(i) Update moisture content with remote station input, and sensing input.

6. Ground Surveys

For economic reasons, ground surveys must be kept to a minimum; it is expected that technological advances in remote sensing by 1985 will reach such a degree that a fiscal saving overall can be made.

7. Special Vegetation

One topic that remains to be covered is the sensing of special landscaping vegetation as applied to the intrusion of fire around wildland structures. These species of vegetation are succulents called "ice plants." Their distinguishing characteristic here is the reduced possibility of ignition due to their extremely high water content. This property suggests that ice plants will strongly reflect infrared radiation--much more than the typical forestry species. This fact coupled with their nearness to wildland structures would reflect a high truth value in the imagery used to detect them. Although there are no investigations in this specific sensing area, at first glance, there seems a high probability of success in employing remote sensing for ice plant detection as applied to an integrated fire control system.

H. Surface Feature Sensing

1. Man Made Features

Figure 3.6 shows an expanded view of this sensing topic. The categories indicated in this figure expand wildland sensing into the area of detecting cultural structures such as bridges, roads, and dwellings. Since some fire breaks, tracks, and roadways are vegetative in nature, there exists an overlap with the previous sensing topic. Applying the results of vegetative sensing to these specific earth features will enable exact analysis to be made as to their proficiency as fire stop boundaries. The only exceptions to this, is where the trails or paths are covered by tree cover or are too narrow to be detected by the resolution of the sensor. (The last case is not a detection problem if the trail is extended over several sensor resolution elements because it can be traced by its deterministic structure relative to the random placement of wildland vegetation.) Excluding the detection of surface features exclusively comprised of vegetation, reduces the sensing problem to the detection of:

(1) paved roads and trails

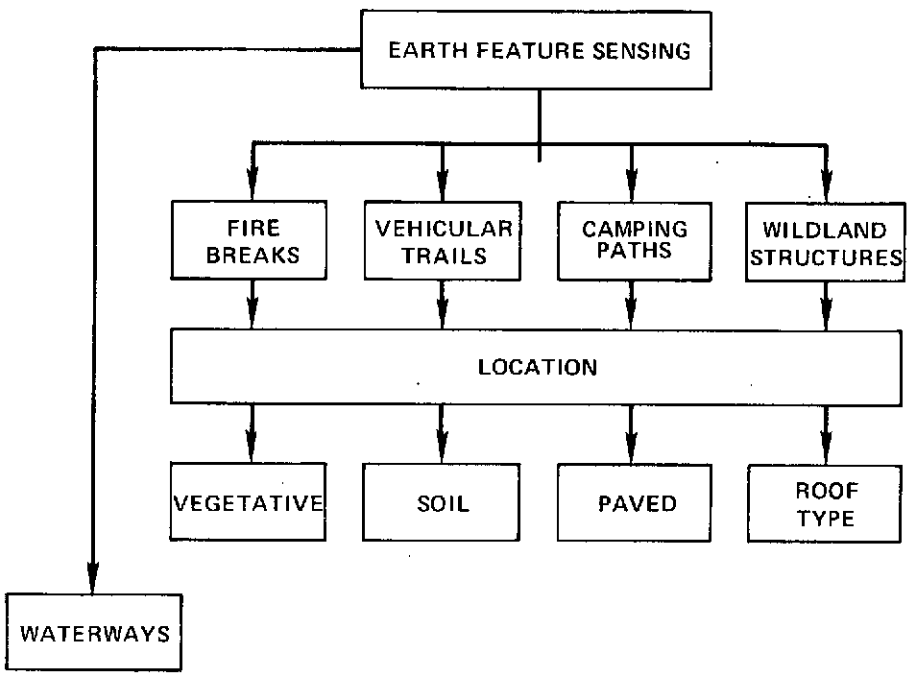

Figure 3.6 Expanded View of Earth Feature Sensing

(2) man made wildland structures, e.g., houses (cultural structures)

(3) bare soil areas

(4) waterways

These topics are individually examined in the following discussion.

2. Paved Roads and Trails

Due to an emphasis of applying remote sensing to urban planning, several investigations have centered on cultural feature sensing such as paved roads, etc. In the wildland situation, pavement would show with clarity against the vegetative background by using certain sensor bands (ERSS, Pischer, 1971; EROIS, Kawamura, 1970). The homogeneous as well as extended nature of paved roads also enhances their detection.

3. Cultural Structures

The predominant factor under this topic is the detection of the location of dwellings and their roofing material types. Roof materials similar to forest materials such as wood shingles can be individually distinguished with techniques established previously. Materials such as synthetic shingles, tiles, and metals must be sensed using algorithms developed for urban planning studies via satellite sensing (ERSS et al, 1971). Since the detection of roofing materials is such a narrow topic in remote sensing, no previous investigations have specifically examined this aspect, but several conclusions can be drawn from previous sensing experiments:

(a) Heat absorption is dependent on roofing material.

(b) Reflectance characteristics of each roofing material may vary differentially.

(c) Moisture holding capability can vary with material type.

(d) Roofing reflection characteristics will vary according to whether they are treated for fire resistance or not.

These characteristics logically lead to experimental investigations to distinguish roof types, i.e., there are enough differentiating properties to ensure a feasible roof sensing algorithm to be developed.

4. Soil Sensing

Current sensing investigations yield a multitude of results in the delineation of soil types (ERTS, Parks et al, 1973). The study by Park et al illustrates how surface vegetation is related to soil in its vicinity. This implies that in some instances conclusions reached in vegetative sensing can imply the type of soil underneath. Other studies (ERAP, Learner, 1968) indicate direct techniques of soil sensing. These investigations point to the fact that algorithms are being developed in bare soil sensing resulting in the delineation of nonpaved transportation surfaces in the wildlands.

5. Waterway Sensing

This area of sensing is so important that many investigations have been carried in detail (ERTS, Water Resources Section). Because of the multitude of investigations in this area, there exist no problems in detecting waterways of any kind, and studies (ERTS op.cit.) indicate it is possible to detect water depths as well. This may have applications in suppression activities where wildland streams are used as water sources.

I. Weather Sensing

1. Fire Triangle

The sensing of vegetation and earth surface features do not yield the complete knowledge which is needed for the wildland fire control system. Looking at the well known fire triangle comprised of fuel, terrain, and weather, one sees that only two of the three terms have been determined so far. The sensing of weather, perhaps the hardest parameter to obtain a realiable measurement on, remains to be covered.

2. Local Weather

Weather sensing in the wildland situation is broken into two segments, micro-meteorology and macro-meteorology. It is assumed that the macroscopic weather sensing is continued into the 1985-1995 era with the introduction of post NIMBUS types of satellites. This still leaves the problem of determining the local weather conditions which are extremely important to wildland fire control management.

3. Micro Weather

To detect micro-weather, and ground fuel moisture, a combination of an active-passive system is proposed, i.e., remote weather sensors placed on the ground transmit measurement information to the satellite. The satellite then relays this information back to prescribed receiving stations. The ERTS A satellite is currently being used to do this through its data collection system (DCS) that relays telemetered information from remote sensing stations on the ground. In the system suggested in this study, a geosynchronous repeater would handle this function. It only remains for the wildland management to determine where and how many (Chapter VII assumes 400 stations in its cost calculations) of these stations are needed to meet their ongoing management needs. In fighting conflagrations, a reserve of these remote stations may be dropped at critical areas to be used for obtaining accurate weather and fuel input for fire spread models.

J. Fire Sensing

1. Infrared (IR)

When aerial views of the wildland are taken by infrared scanning, the fire hot spot will stand out relative to the ambient thermal background radiation. The probability of fire detection vs timber characteristics using a single infrared scanning band has also been examined (Hirsch, 1968). Work with a single scanning band has had inherent problems because false alarms were present from miscellaneous thermal sources. This problem existed because the threshold for fire detection could not be optimally preset relative to all the thermal backgrounds that were encountered.

2. Bispectral

This problem was alleviated by an order of magnitude by using a bispectral scanning approach, whereby two infrared ranges were used to sense the fire and background spectrums (Hirsch, 1971). The fire spectrum signature was different in each band, but the bandground signature was the same. The spectral outputs were subtracted resulting in the background spectrum being cancelled relative to the fire spectrum; thus assuring a high fire to background radiation level. Although it was not mentioned in the report, the bispectral technique is actually an application of a detection algorithm applied to "fire feature space."

3. Single Spectral

The bispectral technique was mainly applied in the detection of small fires; for large fires, single spectral imagery is sufficient because their intensities are large compared to the background. This indicates that using remote sensing in a suppression mode is much easier than in a fire detection mode. This is exactly the mode in which a satellite based remote sensor will be used most efficiently. Bispectral techniques could be applied when it is desired to detect spot fires, although the satellite passover times seems less than optimal for this approach.

4. Vehicle Positioning

Vehicle location at a conflagration remains a problem for the fire fighting management. It is desirable to point out that this is a possible research activity which may be pursued in remote sensing to detect fire fighting equipment. It is suggested that each vehicle would have a specific spectral source which may be remotely sensed by the satellite relative to the fire or wildland background, e.g., bulldozers could have one band of wavelengths and trucks another. Each vehicle could be encoded such that its location as well as fuel status can be detected on a quasi-real time status determined by the satellite passover. The remarks made here are only made as a suggestion of research effort, they in no way should serve as a statement of feasibility.

K. Sensor Requirements (Summary)

The remote sensing of weather, vegetation, and earth surface features complete a troica which can be coupled with remote sensing of fire to provide a base for wildland management and fire control. A combination of these four remote sensing areas can now be applied to the outline given in Figs. 3.1 and 3.2. For instance, remote sensing can be used to determine people management of wildland areas by obtaining the status of vehicles entering these premises. The detection of automobiles, and other vehicles, number of campfires, coupled with a fire danger rating system can be applied to obtain statistics on the use and entry procedures in wildlands. These data combine to provide the solid information that is required to effectively evaluate the results of the math models suggested in Volume I of this study. Given this information, the math model approach gains input validity. The detection of roof types, clearances around structures, and fire retardant vegetation (all shown to be within the capability of remote sensing) can be applied in the administration of zoning burn permits, insurance rates, and inspection procedures. One of the main uses of remote sensing is to obtain raw data and aerial statistics (which seem to be lacking) both at pre and post fire periods to ensure a rational approach in the application of all topics depicted in Figs. 3.1 and 3.2.

Chapter II reviewed the literature showing how current remote sensing techniques could be applied to the wildland fire control system. In order to ensure that these sensing requirements are met, some justification must be given as to what sensors are predicted to be on board the 1985-1995 satellite. This is best done by reviewing what sensors are currently being carried by the ERTS A and what future sensor recommendations are being made now for the 1985-1995 era.

The ERTS A satellite currently carries 7 sensors covering the optical to near infrared band. It is anticipated in the 1980's that 12 multispectral sensors extending the sensor range into the far infrared will be carried by earth resources satellites (Van Vleck, 1973). It is assumed that no active sensors will be on board the satellite because sensor technology (algorithms) would be upgraded to such an extent that they would not be needed. Van Vleck's study shows a strong argument in the use of algorithms in remote sensing. There exists a high probability that algorithms developed for processing sensor data in the higher priority applications will greatly overlap those directly applicable to the wildland management sensing needs described heretofore. This supposition seems quite likely considering the increase in the number of multispectral channels predicted in the 1980's.

L. Communication System

The discussion so far has centered on the sensor requirements of the 1985-1995 time period; how the sensor data is distributed to the various management decision levels has not been determined. The purpose of the next sections is to show how the role of the satellite system is incorporated into the communication system necessary for wildland management.

1. Schematic

The communication system for the wildland management system is shown in Fig. 3.7. Some general comments about the system as a whole are:

(1) The entire system must be digitized due to the emphasis of computer processing.

(2) The most difficult link is from air to ground because of the large bulk of data in bits.

(3) The longest delay time in communication or response time is determined by the air to ground resource data link.

Since the 1985 wildland management system must interface with this communication structure, these comments are applicable to its communication system as well.

2. Interaction

The wildland management system interacts with this communication structure in several ways. It extracts information from both the ground based and satellite based sensors, and it uses the relay satellite (geosynchronous orbit) for a communications relay between the California State Command Center (CSCC) and a Task Force Command Center (TFCC) at a remote fire location. The data coming to the CSCC is assumed to be the same data that is available to all other users of the satellite, and it is at this point only, that special equipment or services are available to wildfire control.

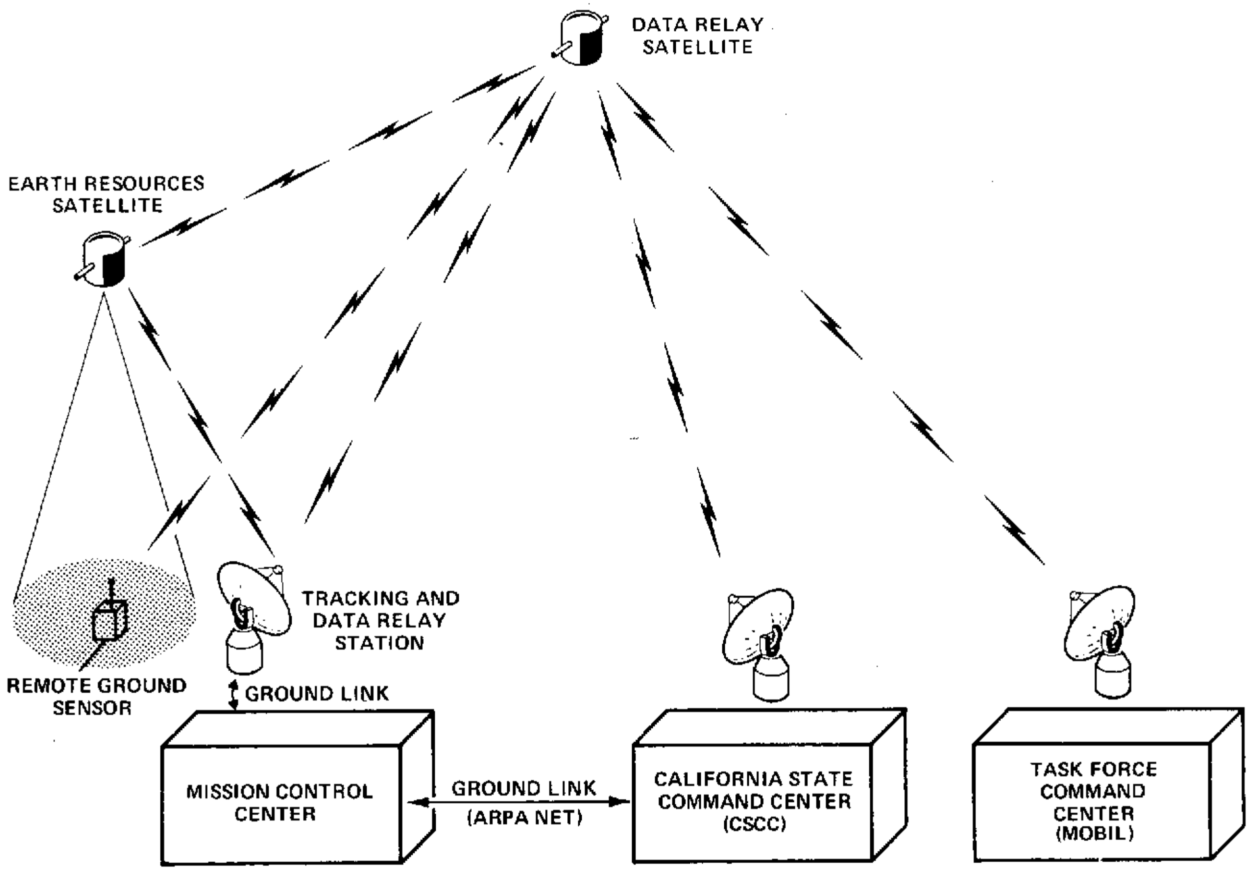

Figure 3.7 Wildland Management Communication System

3. Ground Net

The ground communication link between the national level, mission control center, and the various second tier earth resource users is assumed to be well established at this time. The reasoning behind this is based on the currently available ARPA Net set up by the Advanced Research Projects Agency of the Department of Defense. The ARPA network connects different types of computers located at various branches by means of interface message processors and leased lines capable of transmitting information at 50 kilobits per second.

4. Feasibility

The feasibility of using data acquired by remote ground sensors is well established. Since April 1973, a self-contained remote ground sensor has been sending complete weather and negative fuel information via the DCS channel on the ERTS A satellite. Operations of this type will be conventional by 1985.

5. Command Components

Since the 1985-1995 CSCC wildland management structure is necessarily centralized because of the need for centralized computer processing, there is an inherent difficulty in relaying information to the fire location. The new fire command structure is different from the one in current operation in that the strategic commander is not directly at the fire, but is at the CSCC. The top ranking fire boss is necessarily situated at the CSCC because of his need to see the whole California wildfire picture as presented by the sophisticated data processing and display apparatus used to depict several fires. The subordinate fire management teams headed by Task Force Commanders (TFCC) at the fire, are housed in command modules which display some but not all of the fire information. The Task Force Commanders see their designated and flanking portions of their fire, but not the whole stream of information available at CSCC.

6. Command Module

In order for the Task Force Command Module to function, there must exist two reliable communications links:

Link 1: The command module must communicate with all subordinate units at the fire.

Link 2: The command module must communicate with the remotely positioned CSCC.

Since the command module is mobile and is located near the fire, it is assumed that the classical communication networks that have historically developed will be used in link 1. In the 1985-1995 era, the fire line communication system uses techniques available through Project Firescope.

7. Message Relay

The second link presents a problem because the actual fire location may be randomly placed relative to the CSCC. Conventional communication channels will not work in this situation because there is not enough bandwidth available on the California microwave link for the transmission of display information (personal communication with E. Van Vleck, 1973, Ames Research). Ruling out these possibilities, leads to the conclusion that a satellite relay station is the only possible solution.

8. Geosynchronous Relay

The relay link uses the synchronous satellite that is already incorporated in the system. To lend credance to this communication scheme, a current satellite system has been developed (but is not operational yet) which has the following operational goals (Elson, 1973).

(a) To gauge the utility and limitations of an air traffic control satellite.

(b) To evaluate the ability of one satellite to track another and serve as a two-way link to a ground station.

(c) To demonstrate the use of a satellite to relay television to remote low cost terminals.

This system is supposed to be operational within a year and uses carrier frequencies between 136 MHz and 6 GHz. Using signals in the gigahertz ranges indicates that sufficient bandwidth is available to transmit all voice and display data. Systems of this kind confirm that the technological directions are definitely leading to the synchronous satellite relay system as proposed.

9. Bit Rate/Ground Resolution

One problem that remains to be addressed is the relation between bit rate and projected ground resolutions. Simply stated, if the elemental sensor resolution at the ground is decreased, more data must be transmitted and stored per unit time. The question remains, can resolution become so small that computer storage, communication bandwidths, and system response times become impossible to achieve.

M. Bit Rate and Bandwidth

The bit rate is tied directly to the hardware limitation of bandwidth by the following relation:

$$H = B \log_2 (1 + S/N) \quad (3.1)$$

where H is the bit rate (bits/sec), B is the bandwidth (Hz/sec) and S/N is the signal to noise ratio. This information theory equation indicates that for a fixed S/N, the bit rate and bandwidth are linearly related. In the following discussions, bit rate and bandwidth are assumed equal $(S/N = 1)$.

N. System Response Time

1. Process Time

Assuming that an instantaneous field of view 3 to 4 meters on a side is used to cover the 5550 kilometers by 4000 kilometers United States, there would be on the order of 2×10^{12} elemental areas. If we use 5 bits to encode the information for each elementd area, we have 10^{13} bits of information to be processed and transmitted. At today's state-of-the-art transmission rate (10^7 bits/sec) or the 1990 predicted rate (10^8 bits/sec) it would take excessively long time for complete transmission. There are several methods that will need to be considered in order to conform to the constraints of the communication rate limitation. Following are obvious possibilities:

(a) Use low resolution data except when better is needed.

(b) Install data processing capacity on the satellite to scan the total data, searching for specific characteristics such as fires, disease, or whatever else may be desired that has an easily recognized signature.

(c) Install processing and sufficient storage capacity on board the spacecraft so that it will transmit only changes in conditions.

2. Built-In Delay

The built-in response delays in the communication system are shown in Fig. 3.8. This figure indicates all the ways in which the data display at the CSCC may be time delayed. Reviewing this figure and assuming there are no computer storage problems confirms the conclusion the greatest time delay in the system occurs from data transmission to ground facilities T_4.

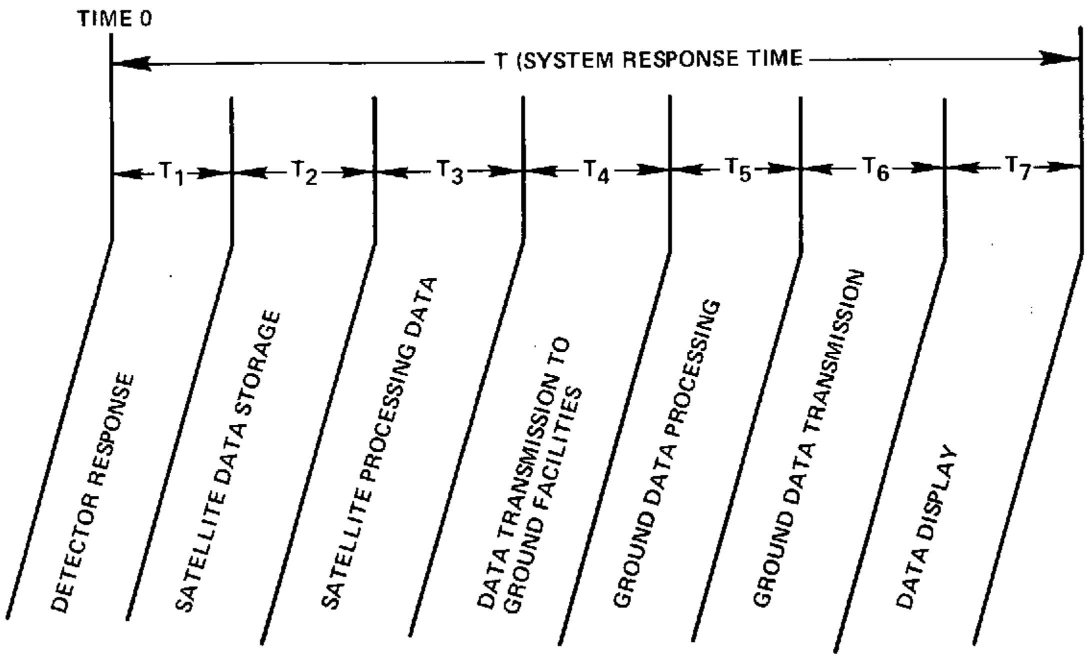

Figure 3.8 Components of the System Response Time

(a) To determine T_4, the bit rate H and N, the total number of bits, must be found and substituted into Eq. (3.2)

$$T_4 = \frac{N}{H} \tag{3.2}$$

(b) N is determined from the number of resolution elements R_E and the quantizing steps Q_S in the encoding process, i.e.,

$$N = R_E Q_s \tag{3.3}$$

(c) Since the R_E equals the ratio of the total area scanned A_T, to the area of the smallest elemental area A_R, Eq. (3.2) is rewritten:

$$T_4 = (Q_s A_T / A_R)/H \tag{3.4}$$

Figure 3.9 shows a plot of T_4 vs A_T for various bit rates. Figure 3.9 indicates that for areas of 10^2 km^2, the maximum communication time is 0.5 sec for a bit rate of 10^8 bits/sec. Van Vleck (op. cit.) predicts this same bit rate in the 1980's, having based his results on technological improvements and international regulations. This bit rate gives response times consistent with quasi real time considerations in the suggested model of the satellite system.

O. Recommendations

This chapter was directed to an overview of the sensing and communications technology predicted to be avilable in the 1985-1995 time period. In particular, it has been shown how the wildlands can be inventoried through a satellite based system that is not specifically designed for use in wildland control. It was shown that given the sensor raw data, that algorithms could be developed to obtain a data base for the wildlands.

The wildland inventory coupled together with a highly reliable fire spread model will allow the wildland fire control management in the 1980's to make decisions that are quite frankly almost impossible to do now. The reason for this is that currently no such data base exists and very little objective data is available about fire spread behavior. The current lack of fire statistics ties the hands of the wildland fire management by not giving them the necessary tools for use in their decision making.

The satellite based inventory system will induce fire management to pursue prevention techniques that otherwise are denied to them. For instance, "let burns" and "prescribe burns" can be carried out with a high

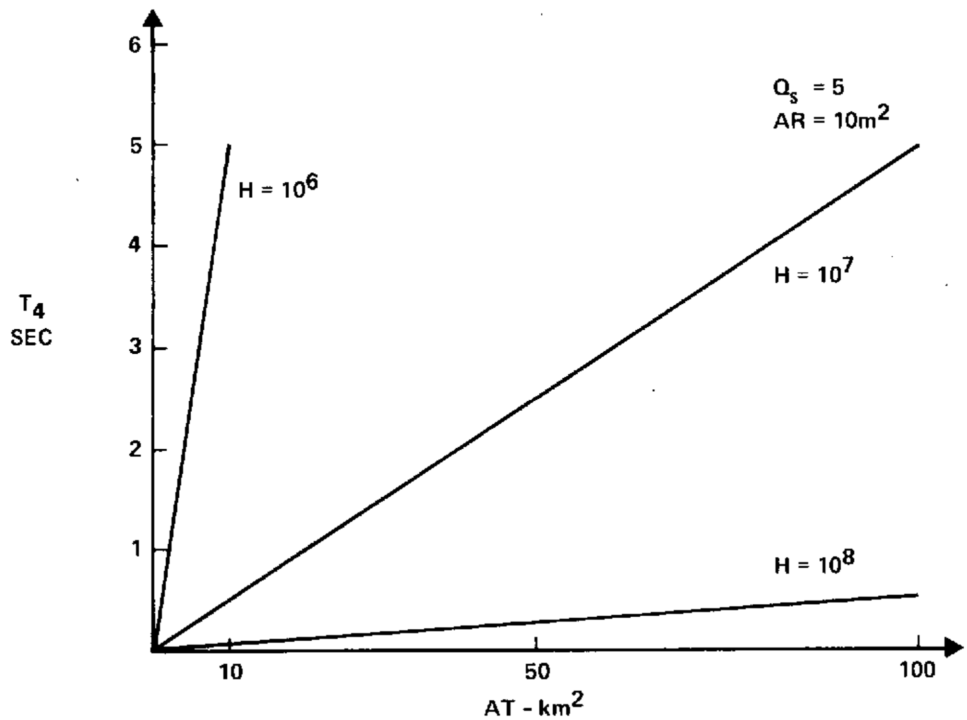

Figure 3.9 Satellite-Ground Transmission Time Vs Area Observed

probability of success knowing a priori that a fire will not "get away." Inspections of wildlands for enforcement purposes, fire insurance statistics, zoning regulation, and use and entry procedures may become standard management practices in this future period.

The predicted future change in management procedures implies that new problem areas will develop. Today's wildland management must be made aware of these potential beneficial changes and direct their resources to pursue them; therefore, it is suggested that the following recommendations be given special attention.

(1) Develop detection algorithms specifically geared to wildland inventory.

(2) Develop new fire management procedures to take advantage of the wildland inventory system and a highly reliable fire spread model.

(3) Develop efficient methods of information storage and retrieval such that fire management decisions can be implemented.

(4) Develop hardware and software to integrate potential satellite systems into the present wildland management scheme.

(5) Initiate research on vehicle location at fires using satellite based sensors.

(6) Develop a system whereby fire behavior statistics can be documented by using the satellite system.

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Chapter IV

INFORMATION PROCESSING AND DISPLAY SYSTEM

LIST OF FIGURES

Chapter IV

INFORMATION PROCESSING AND DISPLAY SYSTEM

A. Information System

The flow of information in the information system is shown in Fig. 4.1. Everything to the right of the dashed line is expected to be in existence during the 1985-1995 time period regardless of any overt participation from the fire fighting organizations. If the fire fighting organization were to participate, then it would be necessary to begin development of the three primary units to the left of the dashed line. These being the

(1) Remote weather stations

(2) California State Command Center (CSCC)

(3) Task Force Command Center (TFCC)

The interface between the CSCC and National Resources Display Center (NRDC) would have to be clearly specified at an early date. In addition, the data interface format between the CSCC and external data gather agencies, such as the Army Map Service for topographt data, would have to be clearly defined.

If the system was used as a national disaster system or as a fire prevention tool, then the CSCC would be a dedicated facility operating 365 days a year. However, if the system was used only for fire suppression, then the CSCC could be reduced to only the specialized interface equipment, with the general purpose computing capability and the communications links being leased only during the fire season.

The remote weather stations would be deployed with the TFCC (see Section B.1) in the region of the fire and hence would be needed only during the fire season. However, they also could be deployed prior to a prescribed burn in a prevention mode if the CSCC was in year around operation. They also could be used in the nonfire season for research into improving the fire spread model.

B. Mobile Fire Control and Display

1. Task Force Control Center

The Task Force Control Center (TFCC) is a mobile van unit which rolls to a Task Force fire camp. It is a weather proof unit which contains communications equipment, graphic displays, computing facility, power supply and working area for the fire boss and a few of his key subordinates. Two cathode ray tube (CRT) displays are provided. They may be operated simultaneously with different type displays or one may be used as a redundant back-up to the other.

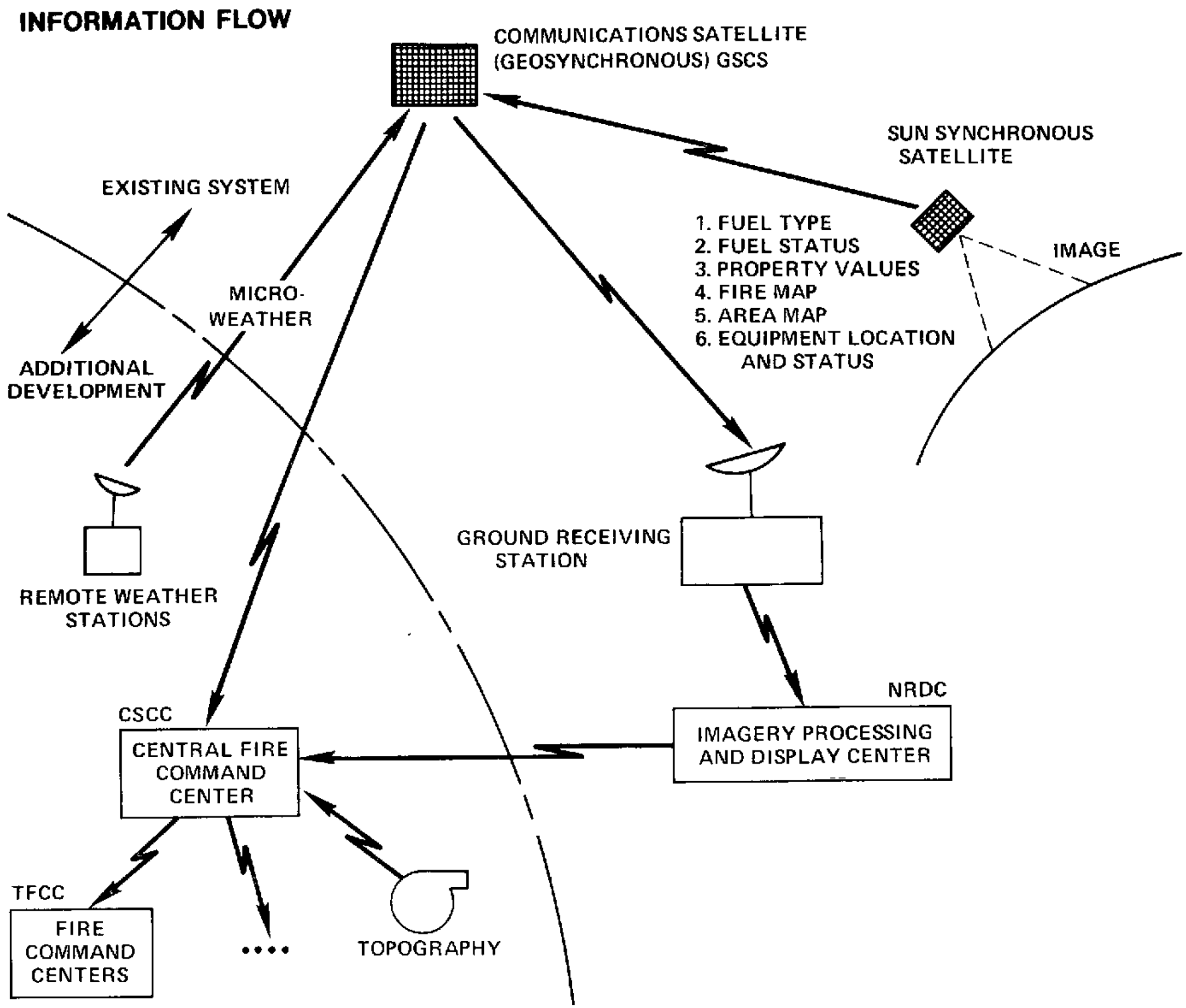

Figure 4.1 Information Flow

The size of the CRT's are 2 feet on the side and bottom with a 4 square foot viewing area. They may be placed in a vertical or horizontal position. After the TFCC is placed in position at the fire camp, a communication data link is established between the TFCC and the California State Control Center (CSCC). This link is via synchronous repeater satellite with a bit rate of 10^6 bits/sec and is established using a 9 foot diameter disk on the top of the TFCC. The reference coordinates of the TFCC are then sent to the CSCC. The fire boss is now ready to use the graphical displays.

2. Interactive Data Communications Philosophy

Usually when one thinks of interacting with an information system, the input means which come to mind are data punched on cards or perhaps a typewriter type keyboard or maybe a teletype terminal. If the interaction is to take place in a human stress situation such as fire control, these means would probably not be satisfactory. The method chosen for this system is the "light pen" concept. The human-machine information interface is designed to be sufficiently simple so that the user can communicate all of the necessary instructions to the information system by simply touching a light pen to the face of the CRT display. This concept is illustrated in Section 4.

In the reverse direction, the information system supplies information to the user only to the detail that was requested. At no time will the user be burdened with a deluge of information which is outside the mental set when the request was made. This is facilitated by a scaling and resolution concept of information display. For example, suppose the fire boss asks for a display of a map with a scaling of 1 in. on the CRT equal to 16,000 ft, then the displayed map will be approximately 91 miles on a side, and since the design resolution on the CRT is 0.01 in. the map resolution will be 160 ft. The information system will only provide map details to the user of a resolution of 160 ft even though the system has information down to resolution of 10 ft. For an example see Fig. 4.2 and Section 4.

3. Displayed Information

The display information has been gathered into two classes. The first class is that information which is pertinent to assessing "what the situation is" and the second class as to deciding "what to do." The first type display is called a MAP. A MAP display shows:

(1) Water (BLUE)

- (a) oceans
- (b) lakes
- (c) rivers
- (d) smaller tributaries

SCALING AND RESOLUTION

SCALE REDUCTIONS	1" ON SCREEN EQUALS, ft	SCREEN WIDTH EQUALS ≈, mile	RESOLUTION, ft
0	16,000	91	160
1	8,000	45	80
2	4,000	23	40
3	2,000	11	20
4	1,000	6	10

Figure 4.2 Scaling and Resolution

(2) Roads

(a) U.S.
(b) State (YELLOW)
(c) County
(d) Unclassified (GREEN)

(1) access
(2) fuel breaks
(3) logging roads
(4) trails (PURPLE)

(3) Cities (ORANGE)

(4) Landing Fields (marked with cross)

(5) Fire Perimeter (RED)

(6) Burned Areas (BLACK)

The second type display is called a PREDICTED FIRE PERIMETER and it shows

(1) Topography (BLUE)

(2) Roads (YELLOW, GREEN, AND PURPLE)

(3) Mobile and fixed equipment locations (SYMBOLS)

(4) Property values (ORANGE)

(5) Predicted fore perimeter for specified time (RED)

Note that the various types of information are given in colors. The CRT's have three primary colors with all of the various combinations and shadings possible.

4. <u>An Example</u>

Once the TFCC has been placed in position and the communications link with the CSCC established, the fire boss can now ask for displays of the command control situation. The initial display is shown in Fig. 4.3. The fire boss must first tell the CSCC what scaling he desires. This is done with the light pen and digits at the bottom of the screen. If he desires a scaling of 1 inch on screen equal to say 16,000 feet, then he would touch in sequence the digits on the screen 1,6,0,0,0, then the decimal point, and finally the E which indicates to the CSCC that the scaling information is complete. Next the dot following the type of display is touched. Suppose the fire boss wants the MAP display, then upon touching with the light pen the dot following MAP, the second display shown in

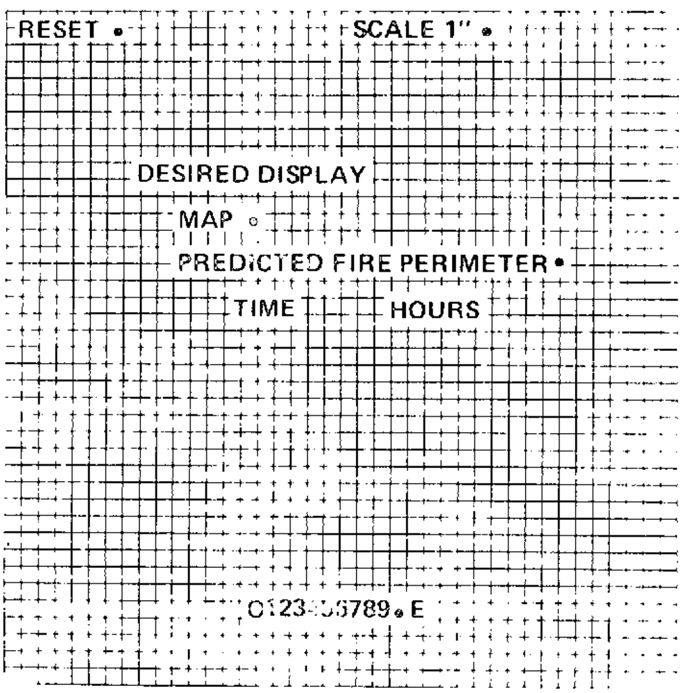

Figure 4.3 Initial Display

Fig. 4.4 will be shown. This display asks the fire boss to touch the screen where he wants the location of the TFCC to appear, suppose at the ⊗. The CSCC will now compute a MAP with the proper scaling and centered around the screen location of the TFCC. The direction of north is always vertical on the screen. The first map is shown in Fig. 4.5. If at any time the user wishes to go back to the initial display, he only has to touch the dot following RESET.

Now suppose the resolution on the first map is not fine enough for the fire boss to see the detail he wishes, then he simply touches the screen at a location on the map where he would like the center of the next map to be. The scaling of the next map will be one half and the resolution will be double. The area of the second map is shown on the first map by the dashed line centered around the ⊗ which indicates the spot on the screen touched by the light pen. Now the second map will appear on the screen with finer resolution and more detail showing. As shown in Fig. 4.2, the first map with scaling 1 in.: 16,000 ft would have a resolution of 160 ft, whereas the second map would have a resolution of 80 ft.

If greater resolution is required, then the screen touching process is repeated. Suppose the fire boss wishes to have the third map centered on the TFCC. He then touches the screen at the TFCC and the region of the second map centered about the TFCC as shown by the dashed line will be expanded to the third map with half the resolution (i.e., 40 ft). Now more detail appears. For example, one can see small tributaries of the water system, small grazing ponds, fuel breaks of over 40 ft in width. The fire perimeter can be seen with more detail with the unburned areas on the interior of the perimeter showing, and also the burned areas are shown in black.

Recall that the size of the displayed map is now approximately 23 miles on a side (see Fig. 4.7). The screen touching process can be repeated twice more to obtain finer resolution. The next touch would reduce the resolution to 20 ft with the displayed map having a size of approximately 11 × 11 miles and finally the last touch would give a resolution of 10 ft which is the limit of the sensor resolution. The resulting map would be approximately 6 miles on a side.

The other type of display which may be selected is the "Predicted Fire Perimeter." Starting with the initial display, the fire boss would first indicate the scaling as with the "Map" display, then touch the dot following PREDICTED FIRE PERIMETER. Next he would indicate the time of the prediction by using the light pen and the digits at the bottom of the screen. For example, if he wished the prediction to be at 1100 hours, he would touch in sequence 1,1,0,0,., E. The display shown in Fig. 4.8 would then come up. This display shows topography, roads, property values, mobile and fixed equipment locations, and the fire perimeter at the specified time. The fire boss now has the option of halfing the resolution as described earlier or he may obtain the status of the mobile or fixed equipment locations by touching the screen in the ◇ for mobile equipment or □ for fixed locations. A status report may be as shown in Fig. 4.9. After observing the status he can bring the map back to the display by touching the RESET dot. The fire boss can now read out the status of other equipment or reduce the resolution.

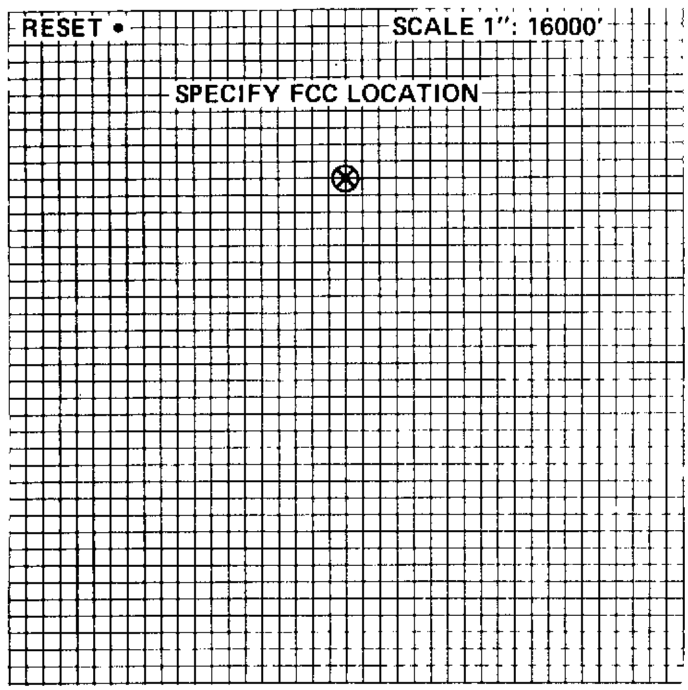

Figure 4.4 Second Display

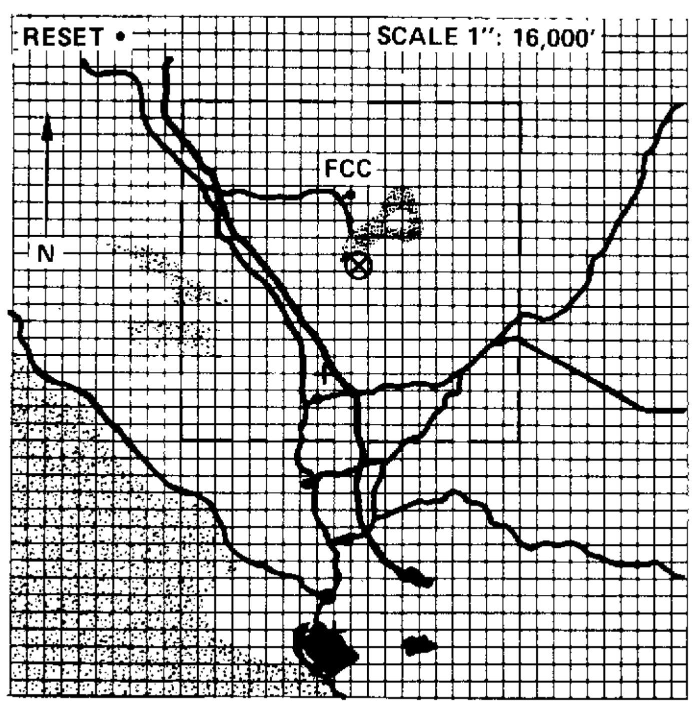

Figure 4.5 First Map

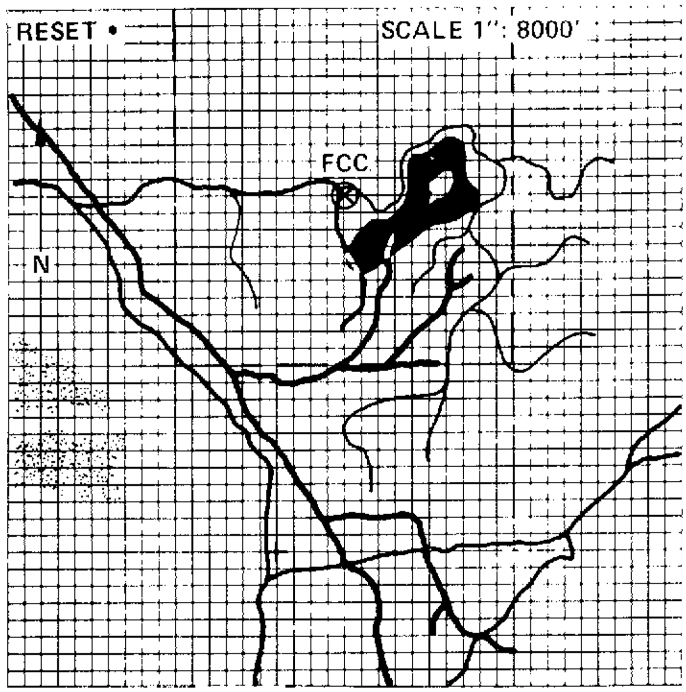

Figure 4.6 Second Map

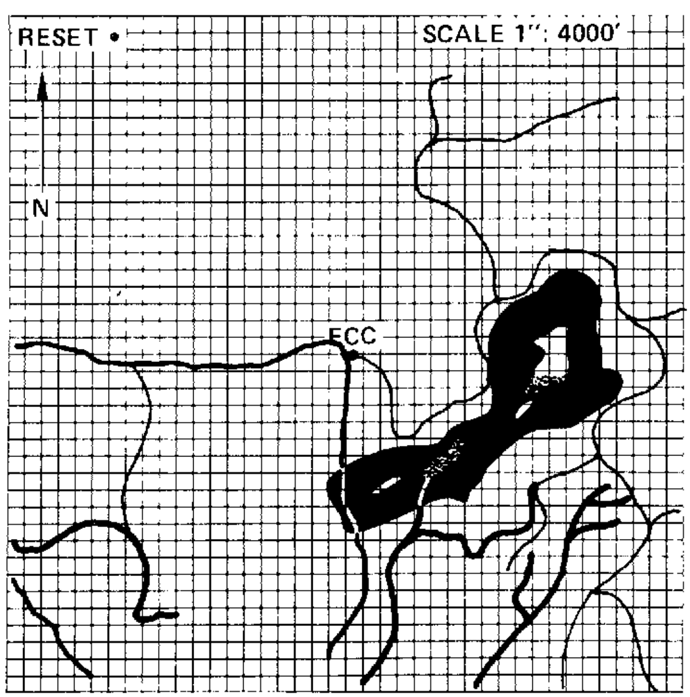

Figure 4.7 Third Map

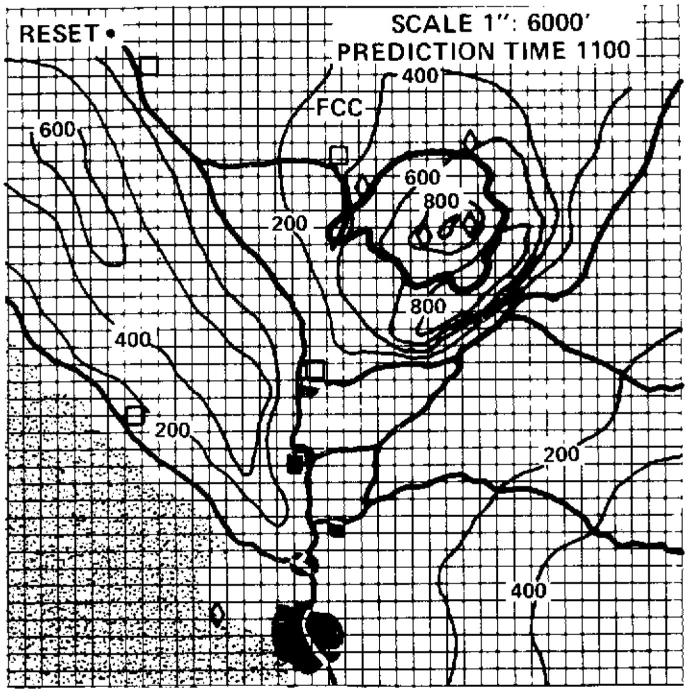

Figure 4.8 First Predicted Fire Perimeter Map

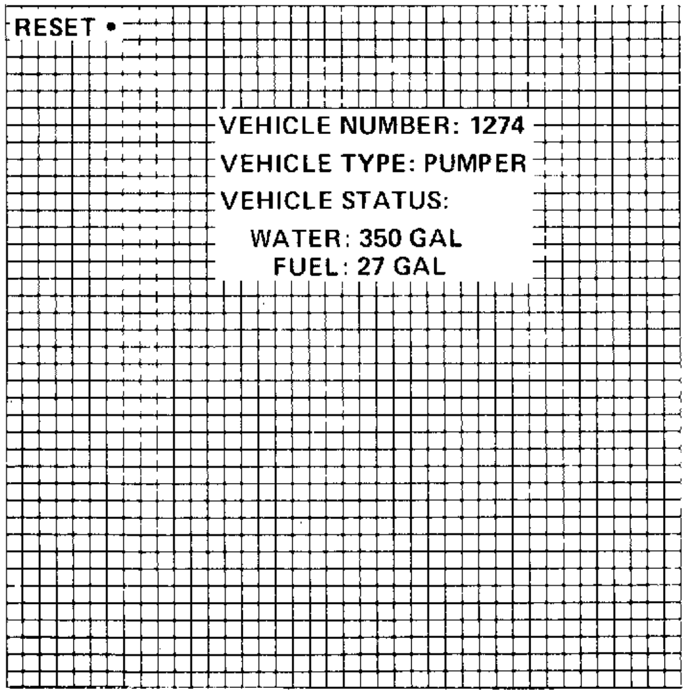

Figure 4.9 Vehicle Status Display

C. Feasibility

The 3-color CRT displays with the resolution described in the previous section are presently available. To bring up a display would require 10^7 bits of information to be transmitted and held in storage. The computing capacity at TFCC, in 1985, would be in the minicomputer class, both in size and cost. The probable cost would be about $3000. The size could easily be held in one rack of equipment. The transmission of 10^7 bits is within the present state-of-the-art.

The most serious technical difficulties would appear at the CSCC. A huge data base at the CSCC is required to back up the TFCC. Some information in this data base would be up dated only yearly or perhaps every 6 months (topography, fuel type, etc.). However, some data would be updated weekly (fuel status, etc.) and some hourly (fire-perimeter, microweather, etc.). With an order of magnitude improvement in computer hardware every five years, it seems that hardware would not be a bottleneck for such updating. However, the historical development of computer software has not been so impressive. Substantial improvement in data base updating and information retrieval software would be required. There is a possibility, however, that some of these functions could be performed with specially designed hardware working with microprogramming to relieve some of the burden from the software.

Chapter V

FIRE SUPPRESSION

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Chapter V

FIRE SUPPRESSION

A. Ground Suppression Doctrine

1. Static Deployment

A review of the California Division of Forestry, "California Aflame!" September 22 to October 4, 1970 Report reveals the magnitude of the fire experience under unfavorable wildfire burning conditions. If we make rough approximations of the areas of wildland to be covered, we see that the total of somewhat less than 1×10^5 miles^2 is in danger. The 1970 experience shows that daily incident rates in this total region was noted as 773/12 days. This makes a 20 incident day not unreasonable. Our problem is to assure coverage on the incident on a "not to exceed" time basis, with the sure knowledge that the sooner suppression action starts, the better.

If we use a basis of 100 task force modular units, then a home base center is within 16 miles of a 1000 mi^2 protection/suppression area perimeter. A doubling of this figure to 200 task force units makes an 11 mile upper limit radius of action from a central base possible. If we take the 100 modules with five divisions in each force, and use a cluster concept for basing them, that is if we have a main base and auxilliary bases that spread out the apparatus over the territory, we enhance the chancesof getting ground suppression forces on the scene in a minimum of response time. This makes a 100 task force distribution more reasonable as a starting assumption.

2. Tactical Organization

We next consider the basic changes in going from present CDF suppression organization doctrine to the 1985 modular task force proposed. Figures 5.1 and 5.2 illustrate the INITIAL ATTACK and REINFORCED ATTACK suppression situations.

3. Response Times

A response time doctrine suggests the following rules:

(a) Basic dispersion of task force components will be made so that in condition (1), at least one light initial attack TF element can be rolled to a fire site any place in the home base region within 20 minutes in Northern California, within 15 minutes in Central California, and within 10 minutes in Southern California.

(b) Dispatch Doctrine will be such that during condition (1) fire danger at least 50% of force is 2 minute ready;

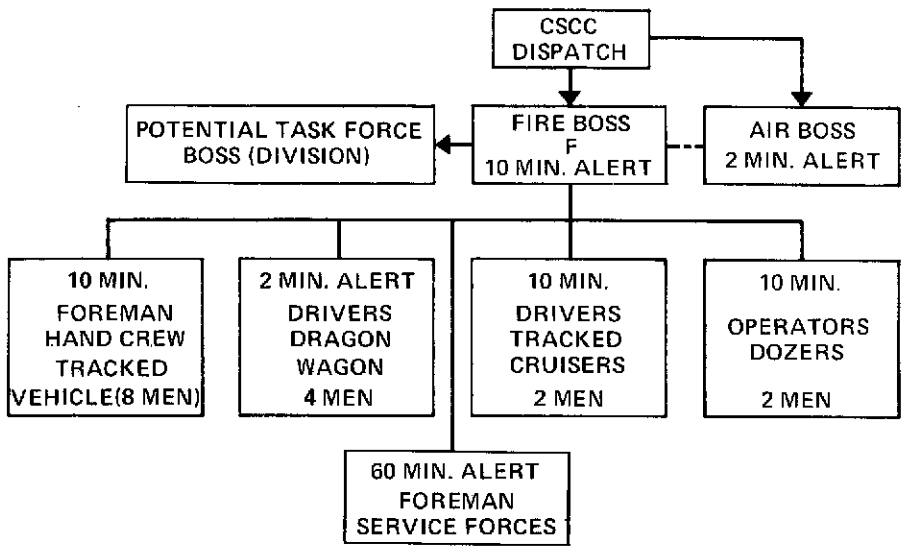
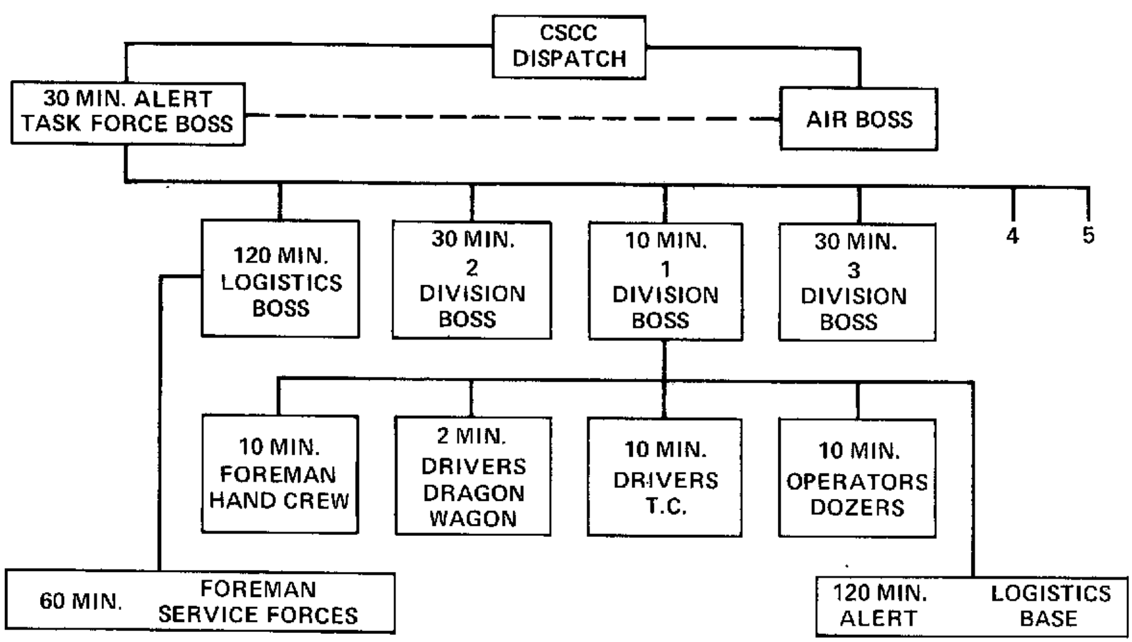


Figure 5.1 1985 Response Time Initial Attack



1st DIVISION RESPONDS TO SCENE	10 MIN. ALERT
2nd DIVISION AND 3rd DIVISION	30 MIN.
4th DIVISION AND 5th DIVISION	60 MIN.

Figure 5.2 1985 Response Time Reinforced Attack

Condition (2) fire danger at least 75% of force is 10 minute ready;

Condition (3) fire danger at least 90% of force is 20 minute ready;

Condition (4) any piece can roll within 60 minutes or is counted "out of service and not available."

(c) The CSCC computer is aware of all equipment availability statistics on a real time basis, and will dispatch accordingly. Home base will update apparatus status every 4 hours during the fire season.

The major difference in this approach from present dispatch doctrine in the California Division of Forestry is that the reinforced attack may be mounted much more quickly if the central command computer evaluates the situation as a high hazard. Shamblin and Jischke have pointed out in Volume I of this study that early suppression effort on a large scale is an effective quenching tactic. It is doubtful that the first apparatus on the scene will arrive quicker in 1985 than now, but the reinforcing efforts can and must be, if more effective fire control is to be achieved.

4. Logistic Services

One new feature of this organization is the designation of a "service force" to provide replenishment of water, fuel, foam, food and other logistic needs as a shuttle service for the deployed task force men and equipment. This service force takes care of the situation by providing stores at certain usage levels as the status reports indicate. These logistic usage data are a part of the task force command situation summary. Each vehicle transmits logistic usage data via satellite link to task force commander and CSCC simultaneously. These requirements are duly noted at the proper places in the logistic base back up chain so as to start the pipe line flowing to fill the needs of the replenishment and suppression forces.

The particular vehicles suggested for these roles and missions and possibilities for new personnel tools and safety items are discussed later in Chapter VI.

5. Older Equipment

It is obvious that there will be a large number of serviceable equipment units which are "modern" in 1973, but will be "older" and perhaps second line in 1985. These older units will form the basic group for the third, fourth, and fifth division deployments in the reinforced task force attack situation. The principle here is that the advanced technology apparatus will be brought into the suppression operation first and the older stuff will be used as back up.

Capital has already been allocated to create the hardware inventory that this apparatus represents, and no further acquisition funding is required. The maintenance and operational costs for these vehicles will continue, and this will be costed in the overall single force Task Force dollar estimates made in Chapter IX.

B. Air Suppression Doctrine

There is no doubt that the quick response time for suppression action to combat the early fire threat will continue to justify the use of a wide variety of aircraft. These services have traditionally been obtained by the wildland fire agencies by contracts with private suppliers and there seems little likelihood of substantial change in this practice during the 1985-1995 era. However, there is a growing tendency to use large aircraft for the dropping of retardant lines, and the U.S. Air Force has been active in recent years in sponsoring the development of special purpose apparatus for quick conversion of logistic support aircraft for this mission. Coupled with this is the continued development of more reliable and larger load-carrying helicopter and STOL aircraft that potentially can have a bigger role in fire fighting operations.

It seems clear that the tactical use of aircraft for laying retardants will, as a concept, continue indefinitely. Aircraft types will be largely what the contract operators will find economically available in the used military market. We have a highly effective daytime capability with World War II aircraft now, but practically no night capability.

The achievement of an effective night capability should be considered as a 1985-1995 potential development. It rests primarily on the achievement of a night-close-terrain-maneuverability and night-navigational accuracy that implies inertial navigation and terrain-avoidance guidance specifications that were designed in attack aircraft of late 1960's vintage. For example, could the current Grumman A-6 navigational electronics be placed in an older S-2 Tracker to achieve a fairly husky load capability and low speed maneuverability needed in wildfire suppression night missions? The A-6 may still be in military service by 1985, but the S-2 or similar types will probably be available for use.

The capability of laying large amounts of retardant materials out of large transport aircraft, such as the MAFF system installed on the Lockheed C130 (Vaughan, 1973) (Fig. 5.3), brings up the question of testing the feasibility of laying temporary wide width retardant lines by flying several of these aircraft in formation over the terrain to be covered. There have been no reported attempts to cover retardant boundaries of 500 feet wide and 3 miles long. If we think of formation flights of five C130 type aircraft per sortie, we could possibly build such a line in 7 to 8 sorties. This might be the type of suppression tactic that would prove effective in a steep terrain area such as the 1973 fire season fires up in the Klamath and Salmon River areas above Eureka. Such sorties could be led by pathfinder aircraft equipped with infrared apparatus to pierce the smoke and establish the fire boundaries, or they could drop on inertial navigation inputs from a lead aircraft.

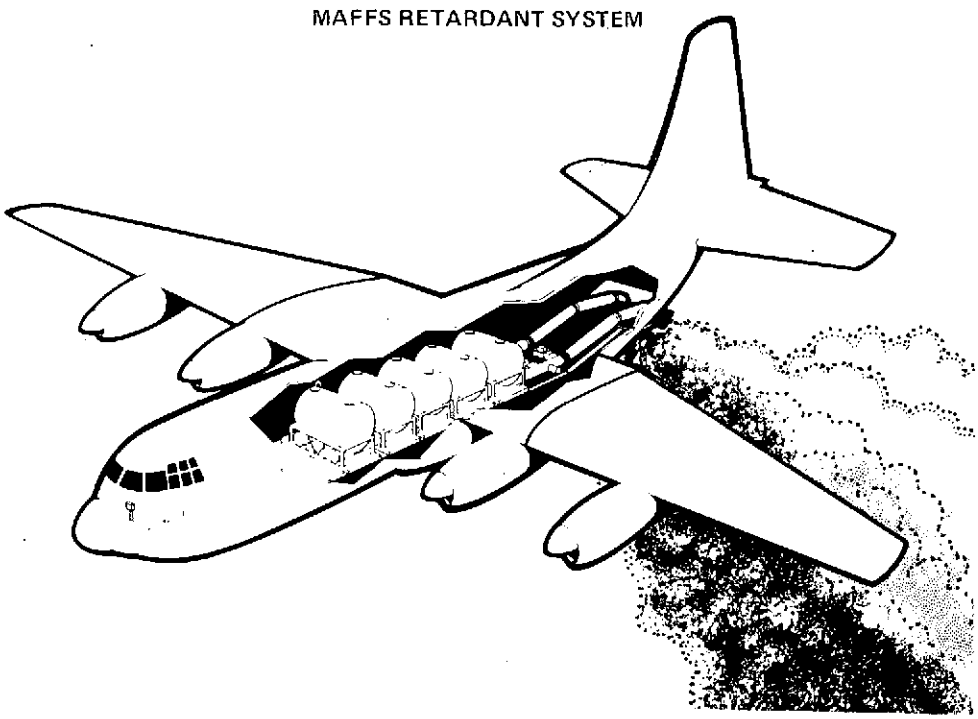


Figure 5.3 Air Tanker

We should also consider the growing utility of logistic support aircraft for replenishment of consumable materials for both the ground and air suppression operations. Helicopters can transport men and materials to the deployed forces and save equipment down times for replenishment rendezvous intervals. For example, helicopters can shuttle fuel, water, and foam containers to fire trucks, bulldozers, and line crews. If we have men deployed with backpack apparatus, helicopters can replenish backpack equipment over scheduled interval reloads. The design and testing of modular supplies to fit such concepts is to be encouraged, for in effect, it amounts to a growth of the helotac capability which is already an integral part of the CDF system.

We have already mentioned the need for continued FIRESCOPE type of reconnaissance of every wildfire into the 1985-1995 era. This typifies the wildfire air force with four major functional missions:

(1) Reconnaissance and link to CSCC for fire spread prediction.

(2) Fixed-wing and Helo suppression by retardant drops.

(3) Helotac mission for transport of men and quenching operations.

(4) Helo and VSTOL logistics support of the ground and air suppression operations.

Other than setting forth in general the 1985-1995 possibilities in conventional aircraft developments, the major emphasis in describing a 1985-1995 wildfire suppression system will dwell on other matters. Cost estimates to support an air night-operations capability will not be seriously attempted.

A discussion of potential RDT&E items for air operations are presented later in Chapter VI; however, the commitment to use the hardware described would rest on considerable further work.

C. Operational Scenario

The following explanation is given to show how the wildfire fighting system under the proposed doctrine might operate in 1985 to combat a forest fire. It is assumed here that PROJECT FIRESCOPE (Hirsch, S., 1973) and FIRESCAN (Hirsch, S. et al, 1968) are complete and all ground equipment has been operational for several years. From this, the command organization has evolved into a central command and the modular task force concept. We have then a California State Control Center, which centralizes the older functions of the "Fire Boss" in the "Campaign fire" situation.

1. Initial Attack Fire

Assume that a wildfire is reported burning at the confluence of the Green and Blue Rivers (nonexistent) somewhere in central California. It is a grass fire with an area of one acre. A report is relayed by telephone to the California State Control Center (CSCC) at Sacramento. At the control center the dispatcher assesses* the situation and dispatches by hard wire an initial attack division of the nearest Task Force (100 such forces are assumed available across the entire State). Since the fire is small and not threatening, no further dispatch action is taken. However, if the micro-FDR (Fire Danger Rating) is high or the hazard deemed great enough, air units would be alerted and/or dispatched. Simiilarly, the dispatcher might have sent to the scene of the fire a Task Force mobile control center.** The module would be for the use of Task Force command and staff in making decisions affecting the firefighting procedure. The module would be in a mobile van and would roll to the fire. (The Task Force command module display has been described more fully in Chapter IV.)

On arrival at the scene, the Task Force Commander (in 1973 known as the Fire Boss) along with his crew make use of modern advanced technology firefighting equipment to quell the blaze (we would expect him to use a lot more foam, for example).

The procedure on an initial attack fire would be much the same as formerly. However, the equipment would be of a later design. In the case of a tanker truck, it would be an off the road type of vehicle and the supply of water on board would be 1200 to 2000 gallons compared to the present 400 gallons. The air attack capability would also be increased by greater sortie assignments.

As the task force is deployed, a scout aircraft would be sent up for immediate reconnaissance purposes. Further, information would be received by relay from the satellite system through advanced technology, giving location information for each vehicle. The satellite would, of course, also intermittently sense the extent of the fire by infrared techniques. After collection of data, the assembled information would be sent from a satellite through several processing centers and then to the CSCC at Sacramento. So while the Task Force is combatting the fire, information concerning the fire size would be available on one hour updates. The location and logistic status of vehicles would be continuously available via synchronous satellite relay both at Sacramento in the Control Center and in the information display at the mobile task force command module. Along with this information would be continuous

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*The assessment would most probably be rearranged and preprogrammed for automatic execution by computer. The assessment would depend on the Fire Danger Rating, the weather, the availability of Task Force Units, and other considerations.

**Assumed developed under project FIRESCOPE and the satellite system proposed in this report as suggested in Chapter IV.

synchronous satellite relay of local weather information. Both the Task Force Commander and the CSCC would work simultaneously from the same input data and would be in constant voice, teletype, and facsimile communication.

Under the scanning system suggested, a satellite passes over a given point on earth only once every hour. After a pass, the collected data would be transmitted via a National Control Center to a Regional Control Center and then to the CSCC and this transmission would cause some delay. (This has been discussed in greater detail in Chapter III.) It is conceivable that with a small fire and quick suppression, the fire would be out before the arrival of the sun-synchronous satellite.

2. Reinforced Attack Fire

Let it now be assumed that the 1-acre wildfire started close to a growth of eucalyptus trees and has spread rapidly into the timber. The single Task Force Commander does not have enough suppression forces. The CSCC should have anticipated such a situation during the initial attack phases and dispatched assistance. Aircraft reconnaissance was initially dispatched and is measuring the spread. It is this input data that is aiding computer controlled dispatch requirements for augmentation of the surveillance forces.

The program at CSCC would switch to the reinforced attack fire mode. In this mode, additional task force units would be ordered to the scene automatically. Air as well as ground forces would be involved. More equipment and more personnel would be vectored to the scene. Each Task Force Commander would have received specific geographic sectors and ground responsibilities as his specific mission task from CSCC. Task Force Commanders would request air help from CSCC, and the CSCC would coordinate air missions through a designated air boss from the overall California wildfire situation displays.

Every hour, updated information in regard to fire spread would be gathered by sun-synchronous satellite and relayed to CSCC and the Task Force Commanders. Wind vector and vehicular location and status would be monitored continuously via the geosynchronous satellite relay station. The California State Command Control Center would be capable of continuously displaying 20 simultaneous fires within the entire State. There would be sufficient electronic displays to maneuver the entire California wildfire suppression organization. The equipment would have not only a capability for 20 fire situation displays continuously, but it could handle a greater number of simultaneous fires with intermittent displays by selective interrogation of particular fire situational data. It would only take about five minutes to establish and display the operational situation for any particular fire or fire sector. The types of displays and the resolution and presentation of the data are covered in detail in Chapter IV.

The fire spread predictions on display would be strictly according to the computer model, which would not necessarily correspond with the spread of the real fire. However, at each succeeding pass of the sun-synchronous satellite, each wildfire display would be automatically updated according to the actual fire as it was on the ground, along with a new prediction.

In addition, the graphical display as envisaged could be selected to show the location on the fire scene of each important item of equipment such as a tanker, command vehicle, personnel carrier, or camp kitchen and the status of replenishment expendables.

Under the service force concept, each task force element would be resupplied by its own shuttle service vehicles. These would be supported from the nearest logistic bases in the area, and each task force home base would have a capability to replenish visting service force vehicles.

3. Summary

Basically, all that the satellite, control center displays and meteorological sensors would do would be to present a great deal of information in a readily understandable and accurate form. It should not be construed from this scenario that all decisions would be computerized or that man would hardly enter the picture. Fire fighting personnel on the ground at the spot are the ones who will still have the task of extinguishing the fire, including mop-up. Experienced personnel at all levels will still be needed. The "fire boss" with many years of experience is still required. His job might be easier from a physical point of view, but the decisions would still have to be made, and he would be the one to make them. The electronic and display equipment would simply aid the Task Force Commander in making his decisions concerning both fire fighting and logistics. While some of the lesser decisions could be programmed into the computer, the Task Force Commander and his staff would still have "override" capabilities on computer decisions.

It is envisioned, further, that the firefighters of the future would also need to be, or be accompanied by, a team of highly trained technicians whose job would be to see that all the advanced technology equipment functioned properly.

It is considered that all of the ideas suggested are technically feasible, although some of the ideas mentioned herein may be ahead of 1973 state-of-the-art. However, as research and development proceed, and particularly if the fire research agencies undertake the task, these ideas for 1985 can crystallize into actuality.

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Chapter VI

POTENTIAL FIRE SUPPRESSION HARDWARE

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Chapter VI

POTENTIAL FIRE SUPPRESSION HARDWARE

This chapter will be divided into two parts. The first will be concerned with a description of available off the road vehicles that require some technical adaptation to the fire fighting role and the second will be devoted to a listing of potential hardware for research, development, test, and evaluation. In the first part, the recommendations for hardware usage are the premises for the estimates of Task Force costs made in Chapter VIII. In the second part, the listing of the fire fighting apparatus infers usage concepts that have not been included in the systems study attempted. Their utility and cost benefits would remain questionable pending systematic review through extended RDT+E programs. They are offered as concept schemes meriting further consideration.

A. Task Force Vehicles

1. Mobile Command Center

One of the major mobile units recommended is the Task Force Command Center. No particular configuration of this vehicle was chosen, but the units required would be packaged into a bus sized motor coach. The FMC 2900R vehicle is an example of existing market hardware (Vaughan, 1973). The cost of such a piece of apparatus, fully outfitted is estimated to be $100,000 per unit (Fig. 6.1).

2. Scout Vehicles

FMC (Vaughan, 1973) has designed a highly versatile and maneuverable scout vehicle. It looks like a modified military jeep and is designated as XR311. It has constant 4 wheel drive and wide tread low pressure balloon tires. It is equipped with skid pans under the entire bottom.

It can negotiate rough, steep, and rocky terrain. The special tires provide excellent traction and flotation and hence it can perform well in mud, snow, and sand. It can ford streams up to a depth of 3 feet. It can travel up to 80 mph on paved roads. The unit cost is from $8,000 to $9,000. There is no doubt that forest fire fighting supervisory personnel would find this vehicle extremely useful. This is the type of vehicle suggested for a division boss, or in an initial attack response prior to bringing in a mobile command unit (Figs. 6.2 and 6.3).

3. Dragon Wagon

Lockheed (Schnebly, 1973) has designed a rubber tired articulated multipurpose vehicle (Dragon Wagon) which shows great potential as

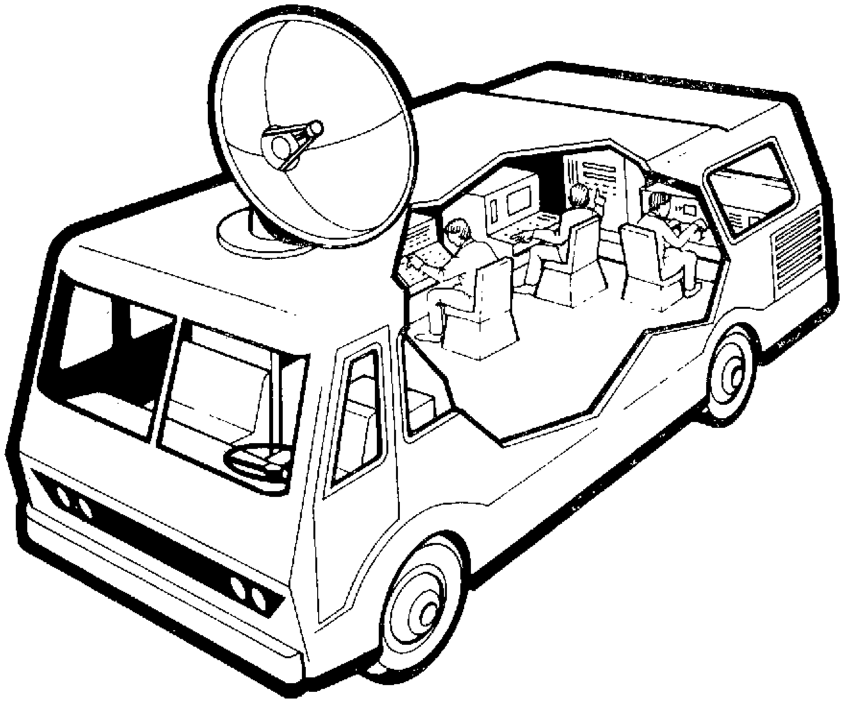


Figure 6.1 Mobile Task Force Command Center

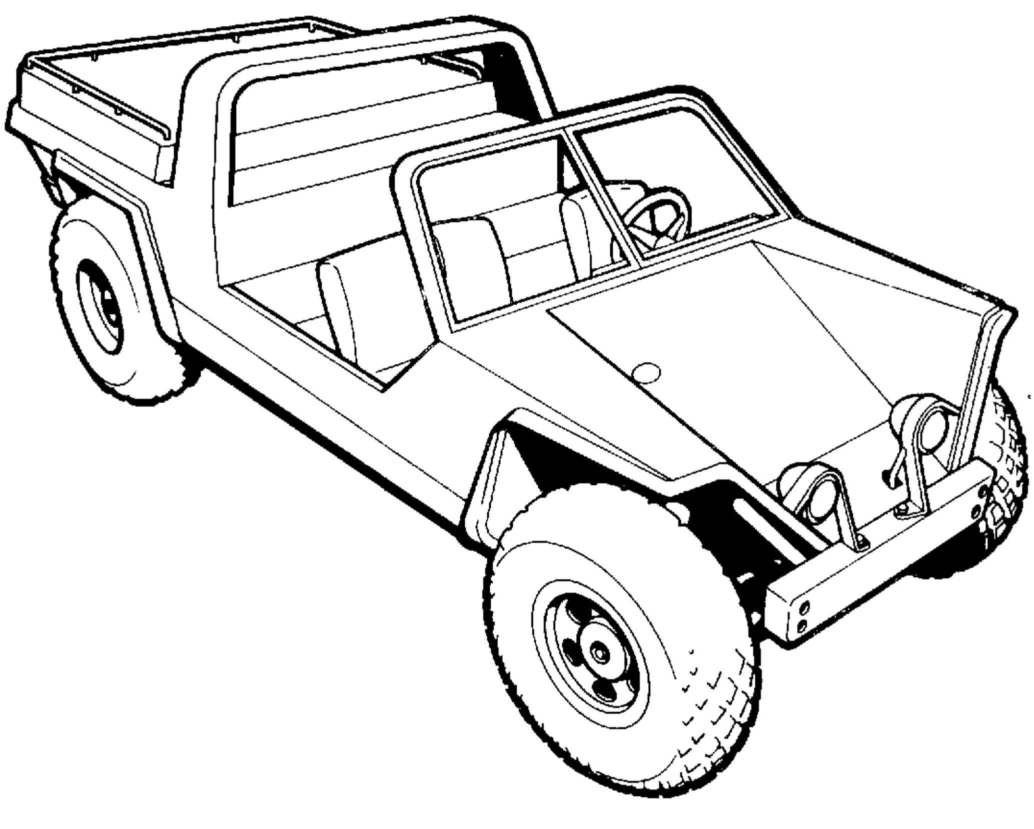


Figure 6.2 Personnel Vehicle – FMC Model XR-311

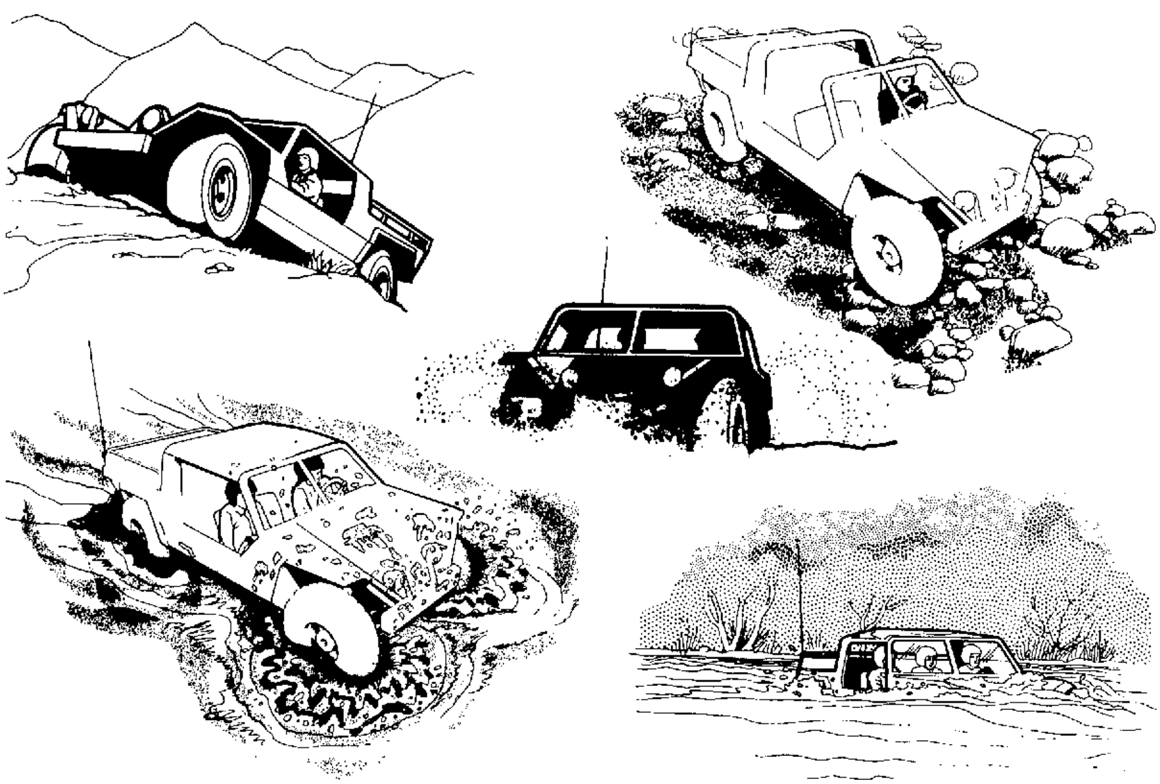


Figure 6.3 Personnel Vehicle Capabilities

an off road fire fighting vehicle. It has eight drive wheels which yield about the same tractive effort as a Caterpillar DC 6. The tire pressure can be maintained as low as 7 psi in steep, rough terrain where traction is difficult, whereas it can be increased to 40 psi for high speed travel on paved highways. This feature plus its articulated chassis and low speed range enable it to negotiate steep slopes, knolls, creeks, mud, snow, water, sand, and rocky terrain.

(a) It can readily be configured to carry three 400 gallon tanks of water or 1000 gallons of water plus 200 gallons of retardant. The unit costs are estimated to be about $60,000.

(b) It can be detached into a tractor element and a rear drive component. A variety of rear drive configurations could be made for off the road wildfire suppression. Among these might be a 3000 gallon capacity unit for service force logistic refueling and replenishment shuttle service. (Figures 6.4 to 6.8 and Table 6.1)

4. Personnel Carriers

FMC (Vaughan, 1973) has a variety of small size tracked vehicles in the M113 series that could be adapted as personnel carriers with concurrent back pack replenishment capabilities (Fig. 6.9). For example, an eight man squad could be supported by such a vehicle for spot quenching and hand lining operations. The tracked vehicle with men would be highway transported to a convenient drop off point, and the tracked vehicle could then take off up to 35 mph over unimproved dirt roads or up trails up to 60% slope and 30% side slope. The foreman of the hand crew would maintain radio communication with his division commander and the carrier would have a variety of tools to use in the single man "one task" situation. It would also have a replenishment capability to reload back pack expendables. This vehicle can also be configured as shown as a "fire wagon" (Fig. 6.10). Unit costs are estimated at $35,000.

5. Timber Cruisers

FMC (Vaughan, 1973) has designed a track laying fire fighting vehicle which is a modification of its military counterpart. It can negotiate a 60% slope with 30% side slope. It has a blade on the front and carries 800 gallons of water. It has a 100 gpm pump, 150 feet of hose, and can pump water from a stream. The unit cost estimate is about $60,000. The specifications are comparable to those of the FMC skidder model 200 CA which are shown in Fig. 6.11 (Table 6.2).

6. Other Miscellaneous Vehicles

The tractor units, high boy trailers, dozers, trucks, and other vehicles required in the quick response division are not special items.

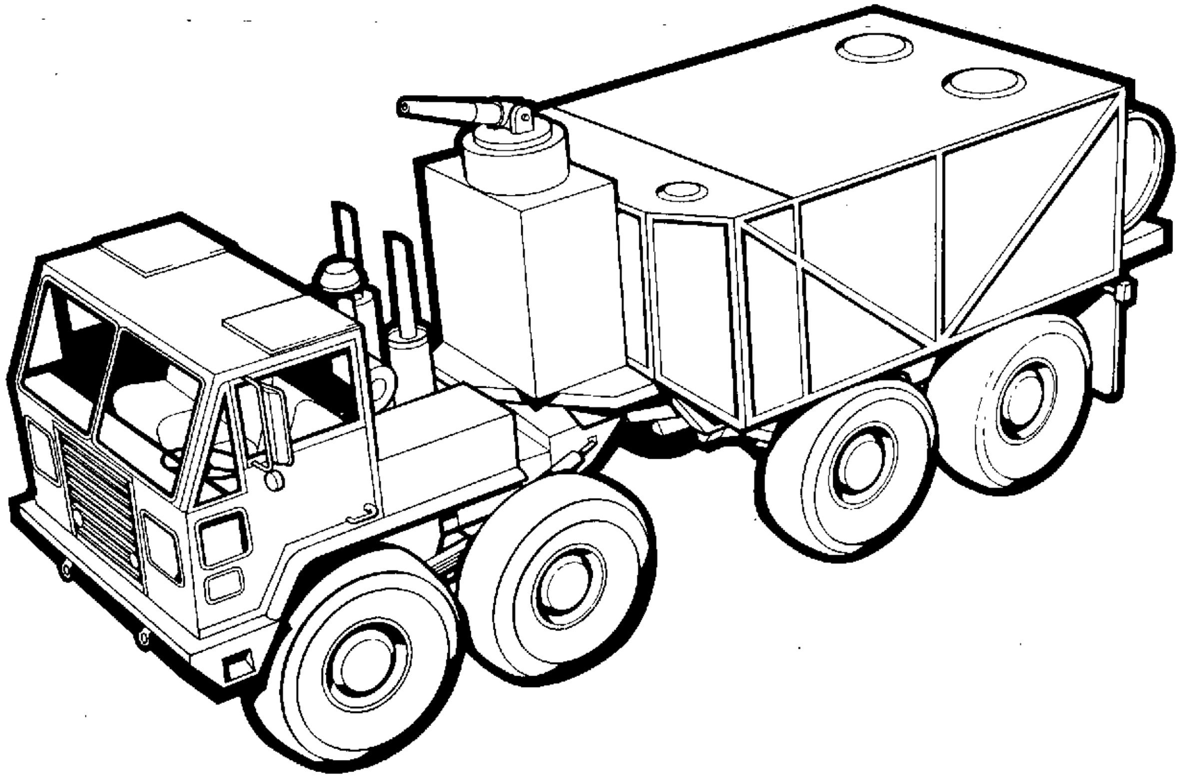


Figure 6.4 Dragon Fire Wagon

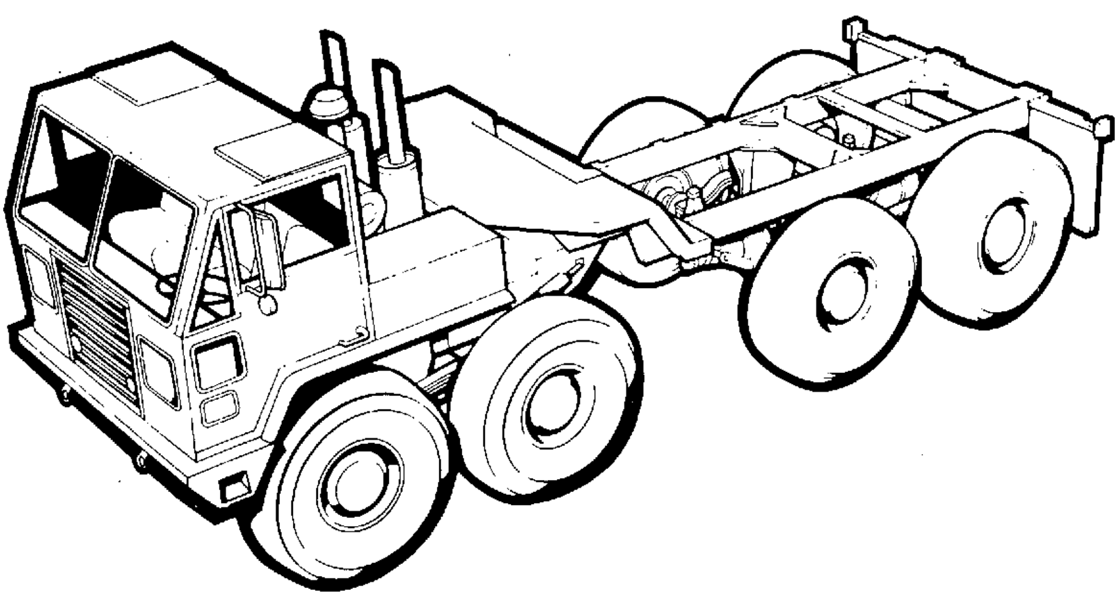


Figure 6.5 View of Chassis

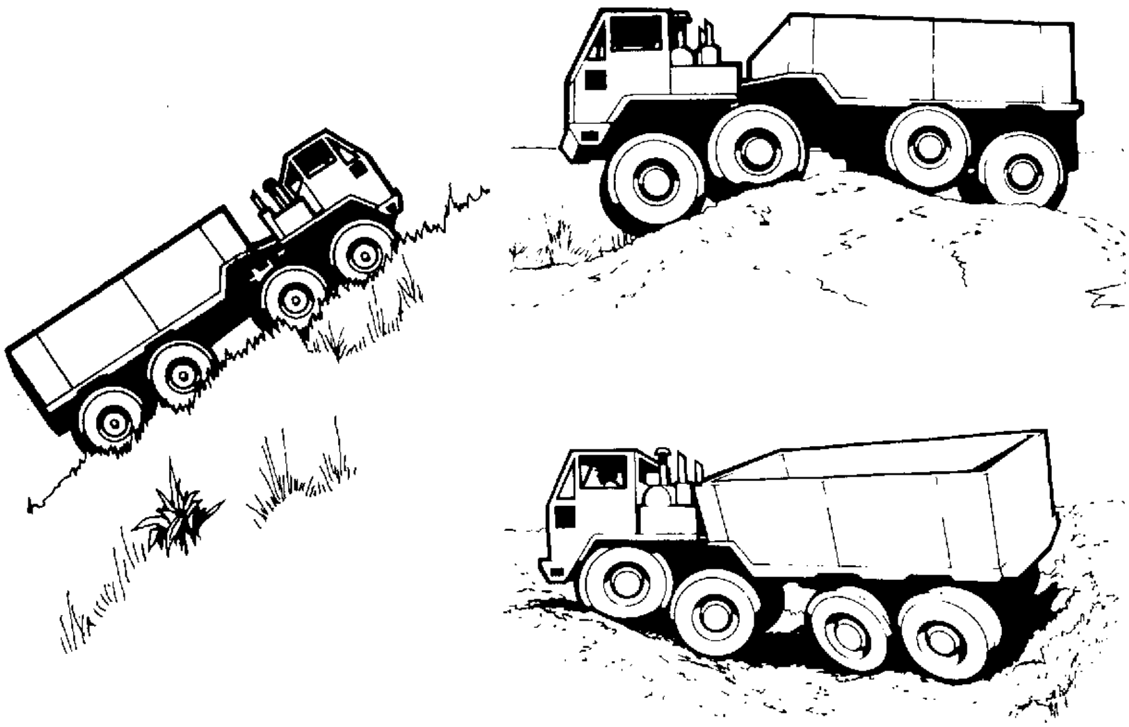


Figure 6.6 Negotiating Difficult Terrain

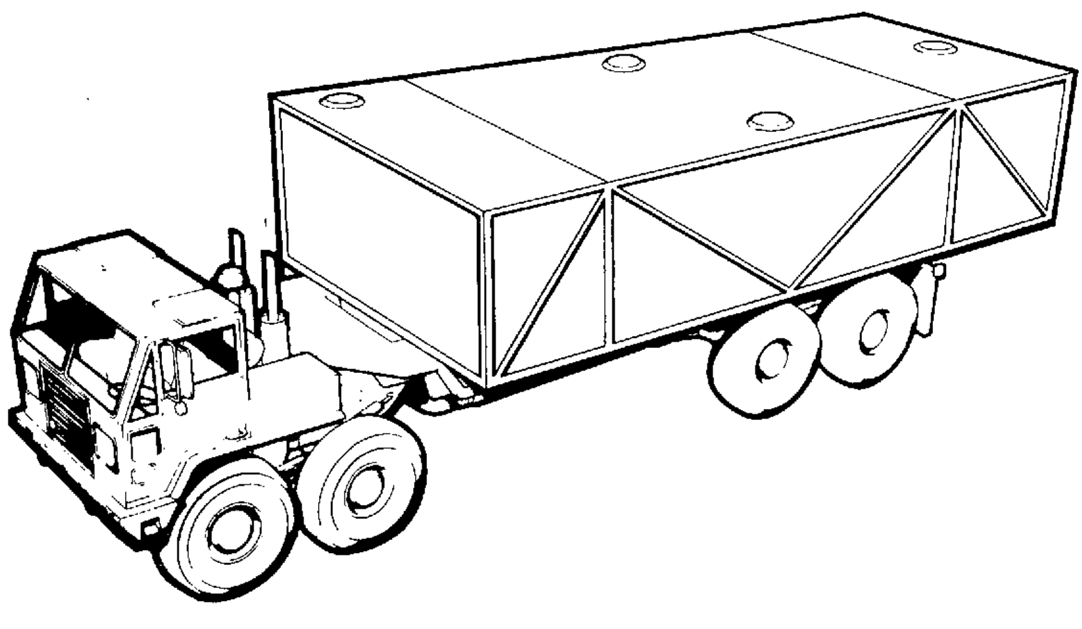


Figure 6.7 Task Force Replenishment

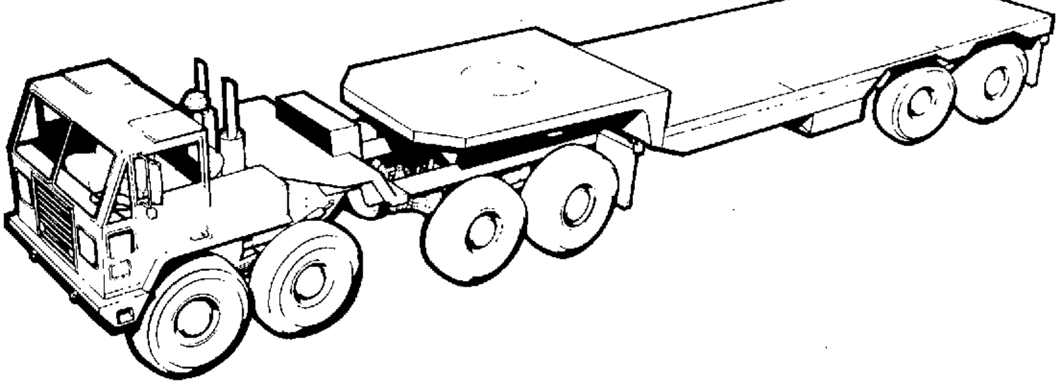


Figure 6.8 With High Boy

Table 6.1

DRAGON FIRE WAGON

SPECIFICATIONS

SPECIFICATIONS

DIMENSIONS

LENGTH, OVERALL	299 in.
WIDTH	96 in.
HEIGHT	109 in.

DIESEL ENGINE
CATERPILLAR MODEL 1160 ·225 HP @ 2800 RPM

AUTOMATIC TRANSMISSION
ALLISON MT650–5 FORWARD SPEEDS, 1 REVERSE

TRANSFER CASE
MANUAL SELECTION OF 8 WHEEL DRIVE OR REAR 4 WHEEL DRIVE. HIGH AND LOW SPEED RATIOS TWO POWER TAKE OFFS.

AXLES
ROCKWELL STANDARD MODIFIED FM M210 TANDEM BOGIES WITH HEAVY DUTY AXLES AND HIGH TRACTION DIFFERENTIALS.

TIRES
MICHELIN 16.00 20XS RADIAL PLY WITH TUBE.

BRAKES
SEALED 14"X3" AIR ACTUATED SERVICE BRAKES ON ALL 4 AXLES. DISC PARKING BRAKE ON DRIVE TRAIN.

STEERING
HYDRAULIC POWER BOOSTED ACKERMAN STEERING ON FRONT AXLES, COORDINATED WITH TWIN HYDRAULIC CYLINDER POWERED ARTICULATION (YAW) STEERING.

SUSPENSION
ROCKWELL STANDARD SIX ROD TYPE WITH TAPERED 3 LEAF SPRINGS.

FRAME
HEAVY DUTY, HIGH STRENGTH, WELDABLE STEEL CONSTRUCTION. EXTRA HEAVY SELF ALIGNING BEARINGS IN YAW AND ROLL ARTICULATION JOINT.

CAB
THREE MAN, STEEL CONSTRUCTION, FULLY INSULATED. TINTED SAFETY GLASS PANORAMIC DRIVER VISIBILITY.

ELECTRICAL
12 VOLT WITH 24 VOLT STARTING. 55 AMP. ALTERNATOR.

CHARACTERISTICS & PERFORMANCE

CURB WEIGHT	19,400 lbs.
RATED PAYLOAD	5 tons
OVERLOAD CAPACITY	8 tons
FORDING DEPTH	45 in.
TURNING RADIUS	26 ft.
ANGLE OF APPROACH	55
ANGLE OF DEPARTURE	65
YAW ARTICULATION	28
ROLL ARTICULATION	15
GROUND PRESSURE:	
RATED PAYLOAD	7 psi
MAX. SPEED	55 MPH
GRADEABILITY	60%
SIDE SLOPE	40%
FUEL CAPACITY	100 U.S. gals.
AMBIENT TEMP.	-65 to +130 F.

STANDARD EQUIPMENT
HEATER/DEFROSTER; ELECTRIC HORN; HEAVY DUTY BATTERIES; PINTLE HOOK; HEADLIGHT GUARDS; HEAVY DUTY FRONT BUMPER; HAND THROTTLE; REAR VIEW MIRRORS; WINDSHIELD WIPERS; SEAT BELTS; CIGAR LIGHTER; ASH TRAYS; MUD GUARDS; ENGINE, TRANSMISSION AND ELECTRICAL INSTRUMENTS; WORK LIGHTS; EMERGENCY FLASHER; HIGHWAY-LEGAL RUNNING LIGHTS, BRAKE LIGHTS, AND TURN SIGNALS; EXTRA HEAVY DUTY AIR FILTER; INTEGRAL TIRE INFLATION OUTLET AND HOSE; AUXILIARY FUEL TANK; OPERATOR AND MAINTENANCE HANDBOOKS.

OPTIONAL EQUIPMENT
WINTERIZATION KIT; FLAT-BED; BRUSH GUARD; AIR HORN; GOODYEAR 48X31.00-20 TUBELESS TERRA TIRES; SPARE TIRE, RIM, AND HOLDING FIXTURE; LOADING DAVIT; ESCAPE HATCHES; STAKE-SIDES; DELUXE CAB INTERIOR TRIM; 20,000 lb. WINCH; SPECIAL COLOR ON CAB; SEMI-TRAILER MODIFICATION KIT.

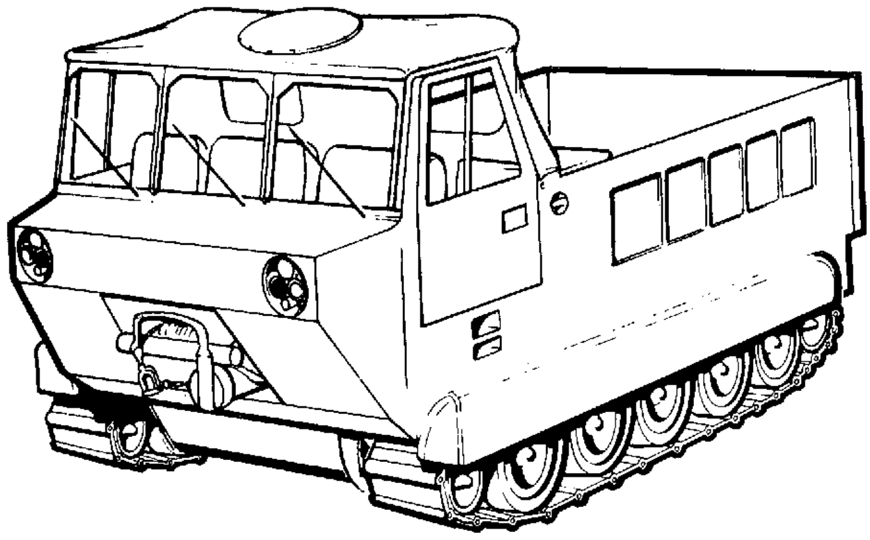


Figure 6.9 FMC Cargo Carrier M548

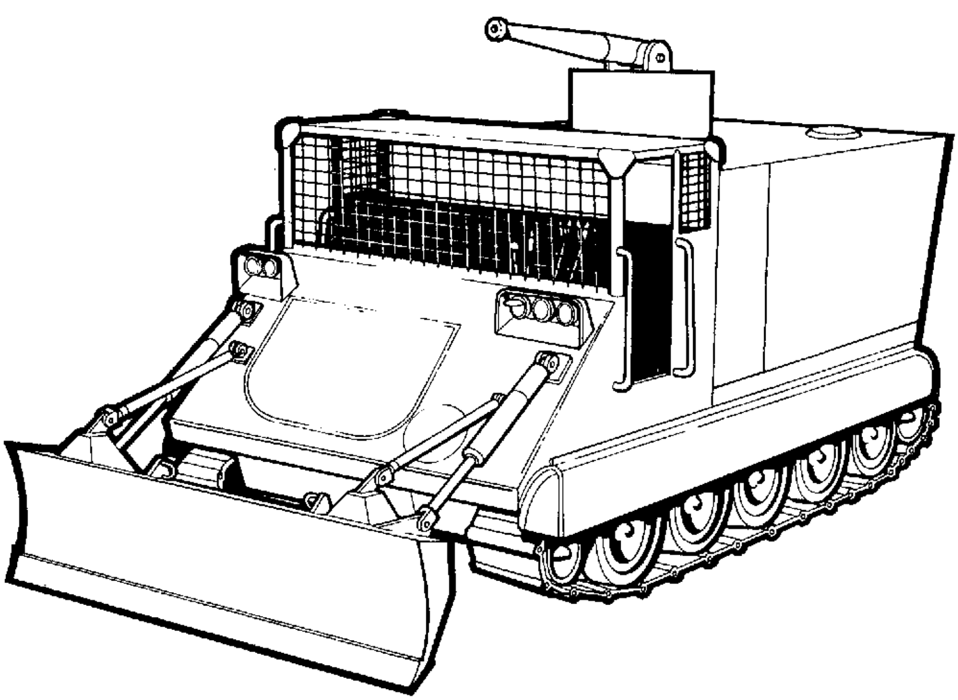


Figure 6.10 FMC Fire Vehicle

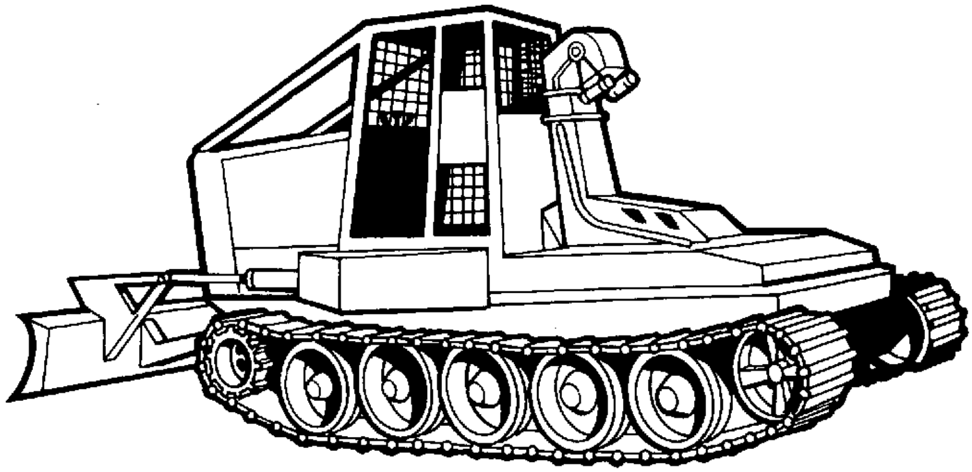


Figure 6.11 FMC Skidder Model 200CA

Table 6.2

FMC SKIDDER MODEL 200CA

SPECIFICATIONS

ENGINE
MAKE: DETROIT DIESEL, MODEL 6V53
HORSEPOWER: @ 2800 rpm 197

POWER TRAIN
TRANSMISSION: CLARK HR 28420
TYPE: TORQUE CONVERTER WITH POWERSHIFT

STEERING:
HIGH SPEED CONTROLLED DIFFERENTIAL
LOW SPEED PIVOT BRAKES

SERVICE BRAKES: MULTIPLE DISC, OIL COOLED, HYDRAULIC
PARKING BRAKES: MULTIPLE DISC, MECHANICAL

PERFORMANCE*
SPEEDS (MAX): FORWARD 1st 3 mph
2nd 5 mph
3rd 9 mph
4th 15 mph

TURNING CIRCLE:
STANDARD 48 ft
WITH PIVOT STEER 25 ft

SLOPES: FORWARD AND REVERSE 60%
SIDEWISE 40%

WEIGHT
NET WITH STANDARD EQUIPMENT 22,200 lb

GROUND PRESSURE
NET WEIGHT 4.7 psi
WITH 15,000 lb LOAD 6.6 psi

They are projected much as they are now. The personnel carriers, timber cruiser, and dozers would require tractor units and high boy trailers to transport them to a convenient drop off point. From there they would proceed over the rough roads and trails at greater speeds than now possible.

The tractor units would unhitch the trailers and return with logistic replenishment, as required for separate task force operations.

B. Research, Development, Test, and Evaluation Possibilities

If we ask "what will the 1985 wild fire suppression hardware look like?", we can make an attempt by looking at what is going on now that the wild fire community generally does not have in an operational apparatus inventory or, for the most part, in their current test programs. What follows in the next portion of the study is a review of some new and some old equipment ideas that have not been reported in a wildfire control context. The ideas presented then can be construed as potential (research, development, test, evaluation) items for U.S. Forest Service laboratory review.

1. Rationale - Line Building

Suppression measures may be divided into two categories, passive and active. Passive methods include such activities as fuel removal by hand crews and machines, backfiring and backburning, and application of retardants to nonburning areas by air and ground equipment. The active measures refer to direct quenching attack with water, chemicals, dirt, etc., using hand crews as well as ground and air vehicles. Much of what follows will be overlapping of the two categories and may indeed apply to either.

(a) Mechanical Removal of Fuel

This is conveniently done with a bulldozer but there are rising complaints regarding the damage to the ecology and the long time required to heal the resulting scars (Stickney, G., 1973).

(1) In spite of the fact that the bulldozer will continue to be a vital fire fighting tool, a more efficient method of accomplishing passive fuel removal is to use a flail head instead of a scraper blade. This consists of a rotating drum fitted with heavy pivot mounted articulated cutters. This is more of a specialty item than a simple bulldozer blade. Potentially, it does a cleaner job with less damage to the surroundings. More testing and development improvements are suggested on the Bomford Highwayman with Bushwacker head (Dahl, 1973) and (White, 1973). The basic machine is illustrated in Figs. 6.12 and 6.13.

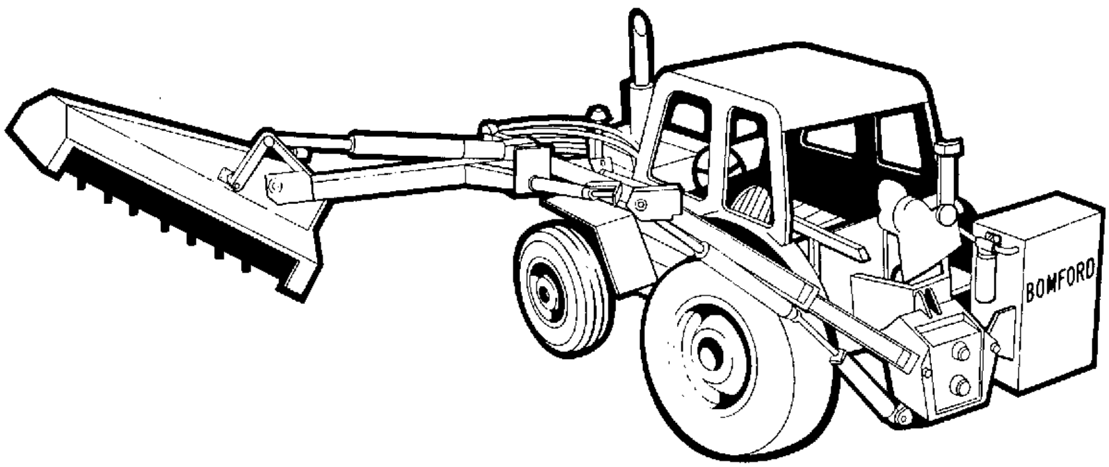


Figure 6.12 Bomford Highwayman Elevated View

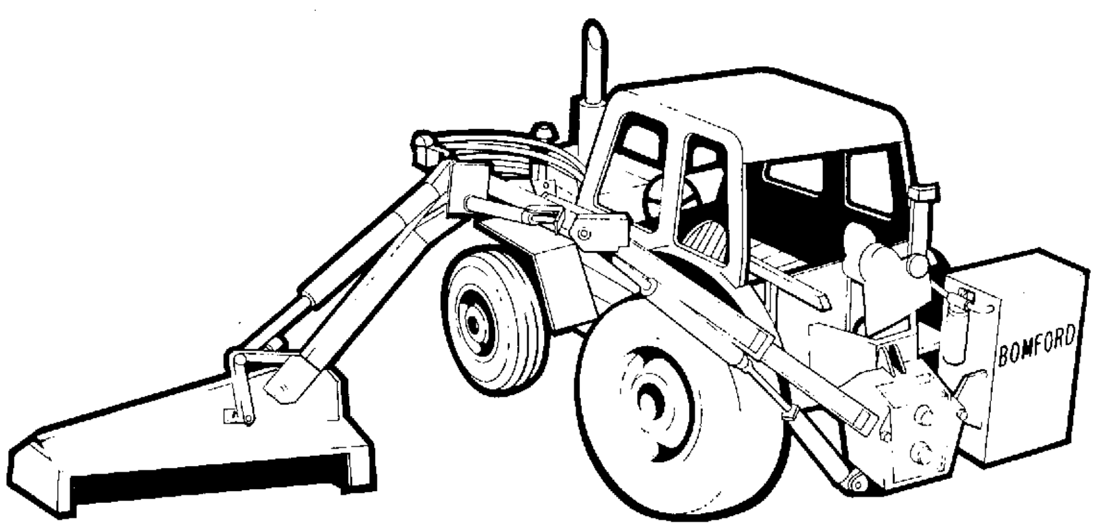


Figure 6.13 Bomford Highwayman with Bushwhacker

Also a sidewinder head is available and should be tested with this machine. The current head is made for moving dirt, and consists of a rotating drum which has a heavy helical cutter attached to its periphery. Other heads such as saws, slashers and mowers are also available for this unit as shown in Fig. 6.4. Such units can be used on just about any tractor having at least 35 brake horsepower and live power take offs. Typical costs run from four to five thousand dollars. The highway department of the state of Washington rented one of these units with a bushwacker head to cut medium brush. The cost was about $75 per swath mile (4 ft swath). The cutting rate was about 4/10 mph, but weather, travel time, maintenance, etc., reduced the average rate to one half of this amount (Fig. 6.15).

(2) Another item of specialty equipment is the Roanoke Robot (USDA, San Dimas, 1968). It is a high speed brush cutter which is hydraulically activated and can be mounted on any standard tractor having at least 35 b.h.p. and live P.T.O. The U.S. Forest Service has tested one which was mounted on an Austin-Western grader. The cutter head consists of a rotating bar containing a pin mounted cutter knife on each end. In principle, this head operates like a rotary lawn mower. (The shielding must be rugged to protect the operator from flying objects, as is also the case with the Highwayman.) A protective cab for the operator is necessary for the same reason. Figures 6.16 and 6.17 illustrate the principle features of the machine.

(3) A procedure to increase the effectiveness of the individual fire-fighter in building fire line would be to equip him with a back pack of line charge explosives. This is proposed as "beads of bombs" and would consist of prima cord fitted with equally spaced explosive cluster units. This is shown in Fig. 6.18. Explosive clearance devices merit further development, testing, and evaluation (USDA, ED+T 2004, 1972).

(4) Along the same trend of thought, we suggest a compressed air activated set of pruning shears. These would greatly increase the speed and safety by which an individual firefighter could cut big brush and small trees. A suggested configuration is shown in Fig. 6.19.

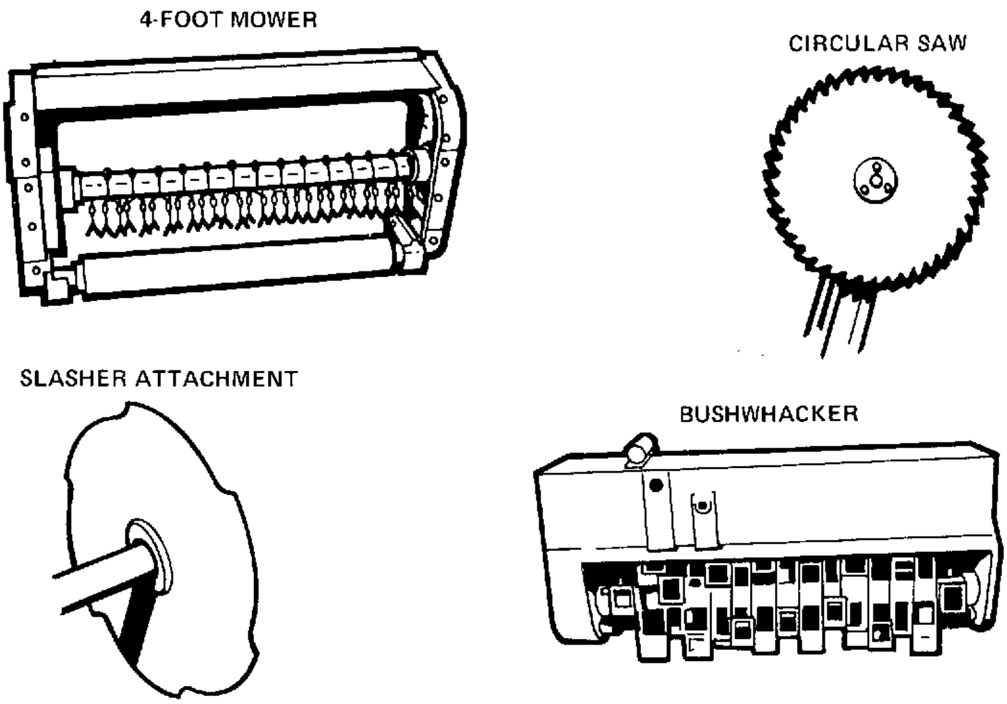


Figure 6.14 Other Heads for Bomford Highwayman

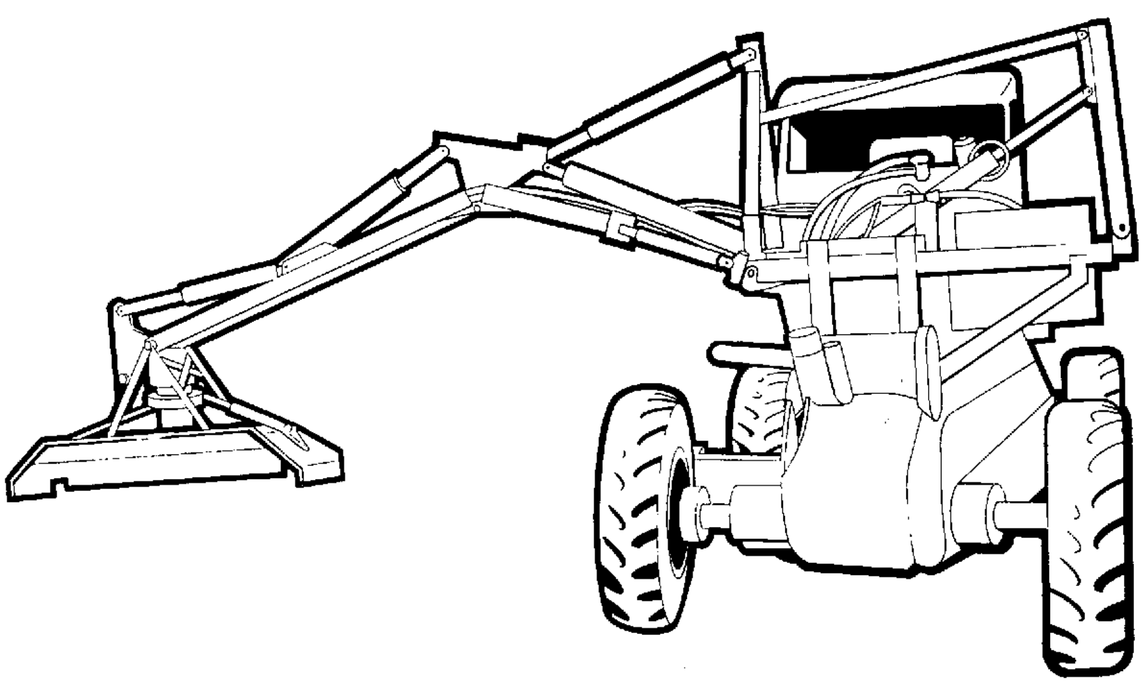
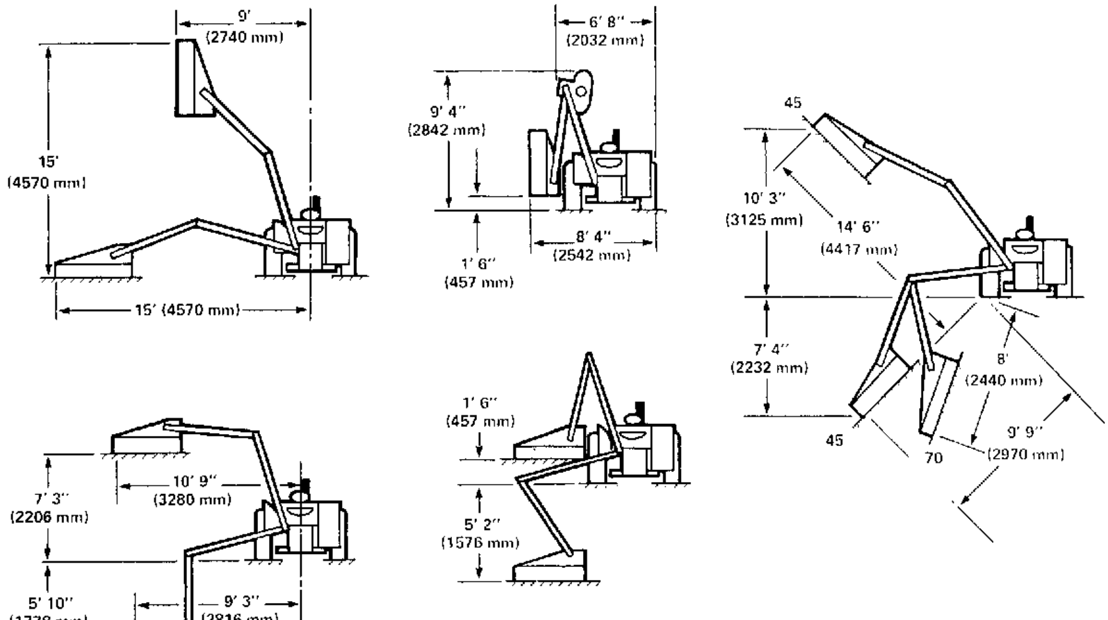


Figure 6.15 Range of Positions for the Bomford Highwayman



ALL DIMENSIONS ARE APPROXIMATE, AND ARE IDENTICAL FOR LEFT HAND AND RIGHT HAND MACHINES.

Figure 6.16 Roanoke Robot

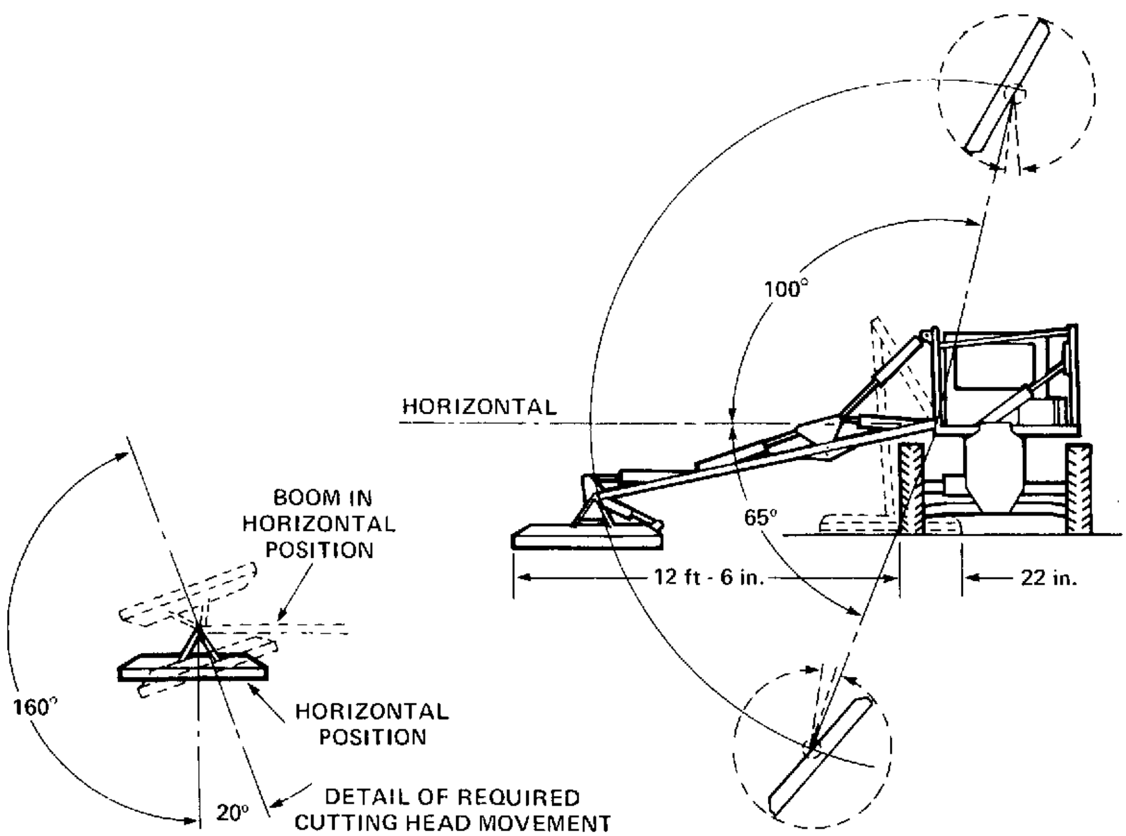


Figure 6.17 Boom and Cutting Head Positioning

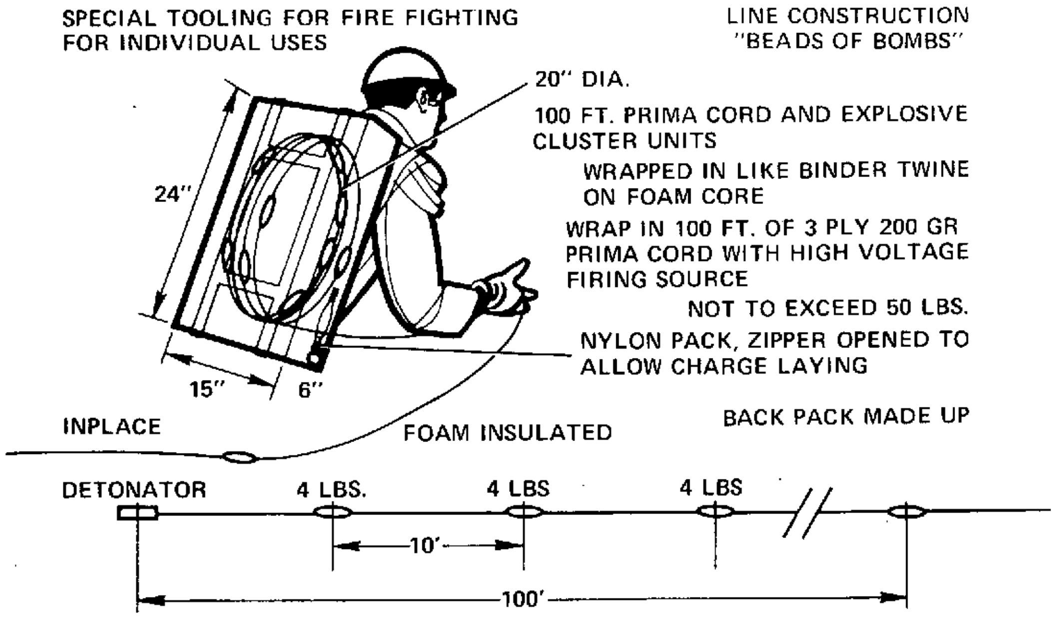


Figure 6.18 Back Pack for Explosives

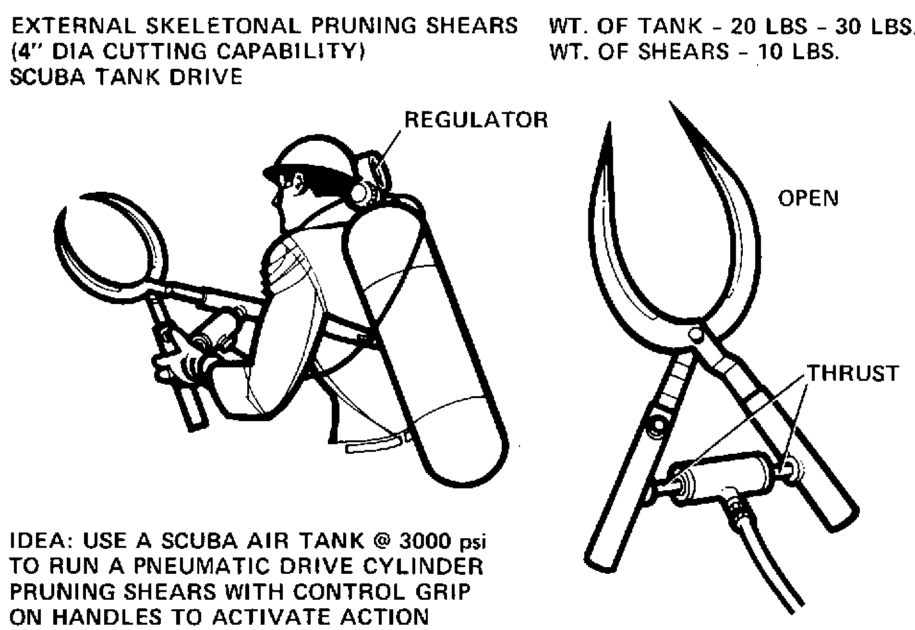


Figure 6.19 Compressed Air Pruning Shears

(b) Retardant Measures

Air and ground vehicles have long been used to cover foliage and structures with retardant. We offer a few more ideas in this regard:

(1) A foam dispensing backpack is suggested for the rapid and efficient application of halogen thick foam by the individual firefighter. It is illustrated in Fig. 6.20.

(2) We also suggest halogen gas foam grenades. These would be small pressurized containers or canisters of foam similar in form to an aerosol bomb. They could be constructed with a low center of gravity and they would, therefore, tend to land right side up regardless of how thrown. They could be thrown by the firefighter carrying a front pack of them, or they could be dispensed from ground vehicles. They might also be fired from a shotgun or ejected by air gun. (Naturally the empty containers would have to be picked up after mopup to prevent littering the area.)

(3) The building of protective lines by other methods than fuel removal and scraping to mineral soil is appealing if only because of the savings of time, labor, and equipment required, as well as the long term negative scars left by the bulldozer. As a matter of fact, bulldozers are sometimes prohibited in some forests for this very reason (Stickney, 1973). In this regard then, a passive "in depth line" consisting of a fluid charged plastic pipe or tubing sprinkler system connected to a fluid source, in conjunction with the application of retardant and/or some foaming material such as Petrolite (Lissant, 1973) might be considered. The use of plastic pipe and tubing for sprinkler systems in structures is scheduled for extensive testing this fall by the City of Palo Alto (Korff, 1973) and (White, 1973).

2. Ground Quenching Technology

(a) The Department of Defense Advanced Research Projects Agency (ARPA) through the General Electric Corporation has been working on a walking vehicle (Liston, 1970) (Mosher, 1969) for use on very steep and rough terrain. It moves by means of large hydraulically activated legs and is said to look like a large animal crawling up the mountainside. This vehicle might be investigated as to its capability for fire suppression in mountainous regions. Several illustrative sketches are shown below in Figs. 6.21 to 6.24.

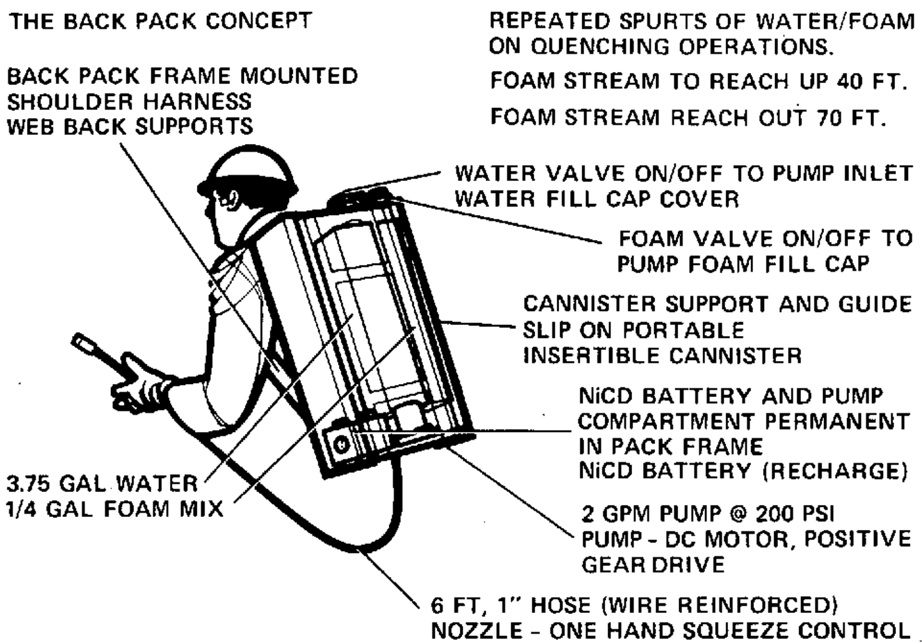


Figure 6.20 Foam-Dispensing Back Pack

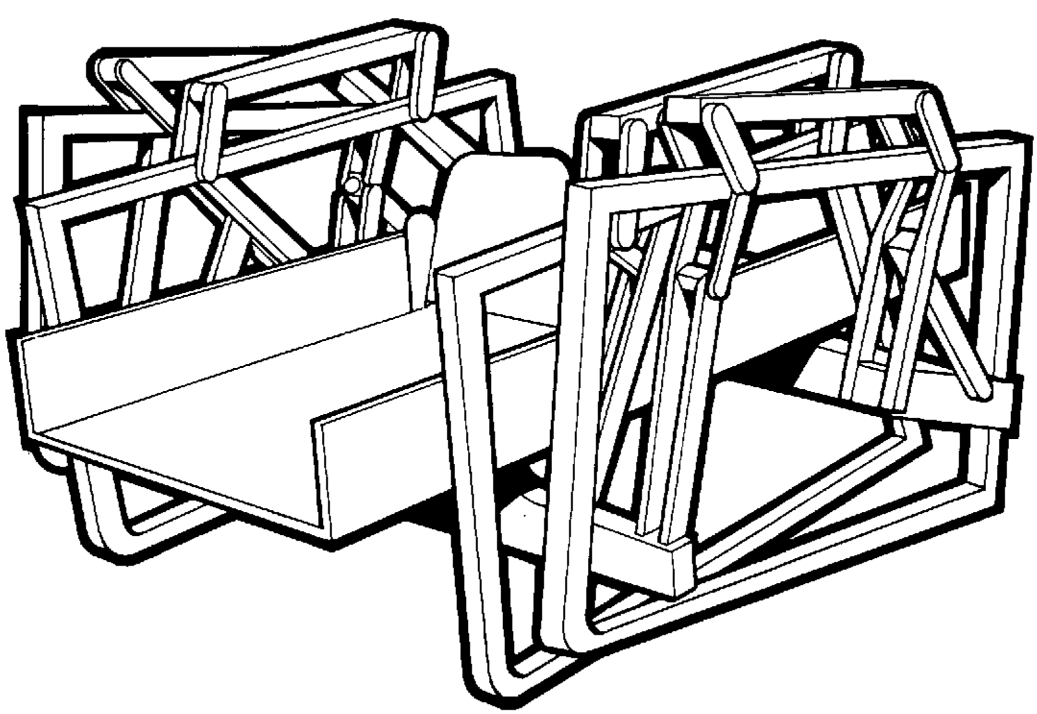


Figure 6.21 Walking Machine Model

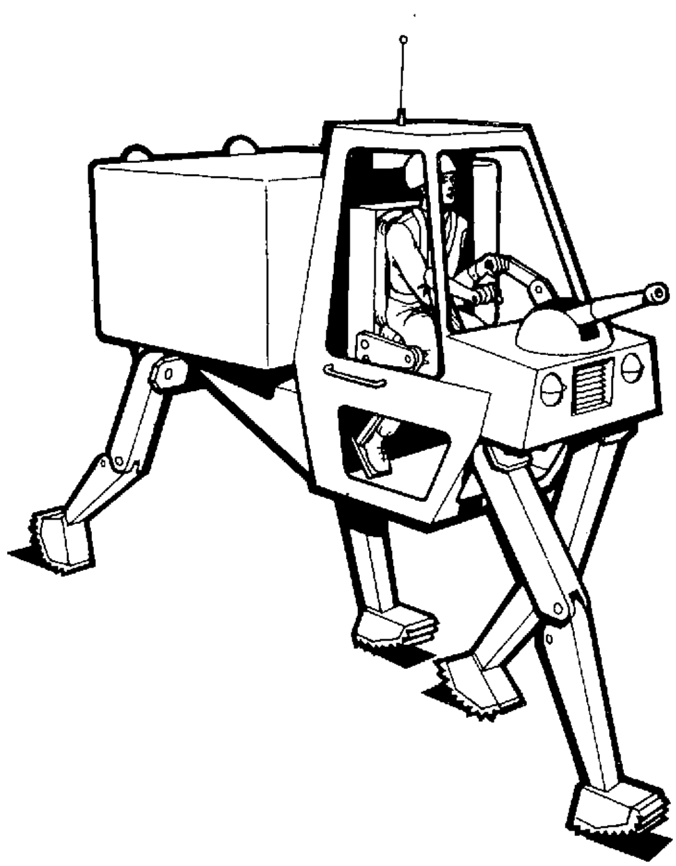


Figure 6.22 Quadruped.

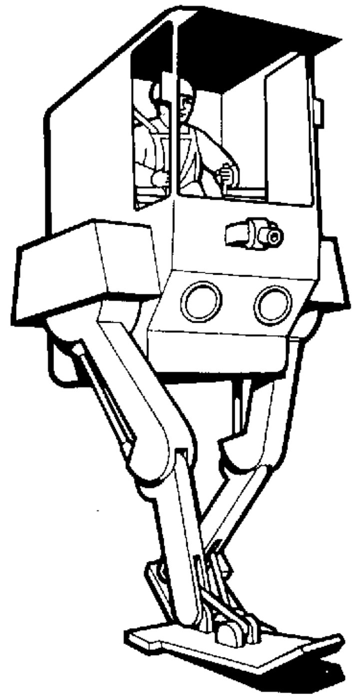


Figure 6.23 Biped

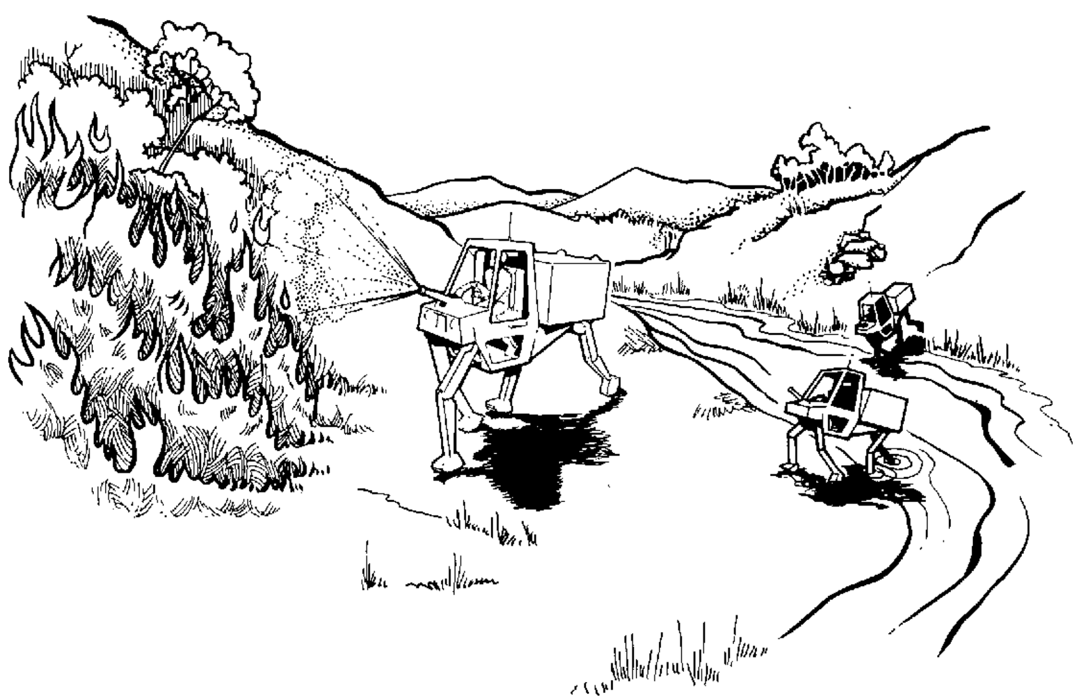


Figure 6.24 Capabilities (maybe)

(b) The forest service has been studying the feasibility of using a tether cable system (McKenzie, 1973) for operating equipment on slopes of 20% to 75%. If a favorable report emanates from these studies, it is recommended that consideration be given to the design and testing of a forest fire fighting vehicle which uses this system. The tether serves to balance or cancel out the down slope component of vehicle weight and hence only normal and tractive components of soil reaction prevail. This is illustrated in Figs. 6.25 and 6.26.

(c) All of the ground tankers or pumper units suggested as task force vehicles have been configured by the manufacturers to carry reels of hose and pumps similar to those on municipal fire trucks. In the case of the municipal truck, it seems proper that it be so equipped since the fire is confined to a structure or structural complex and the fireman may well have to climb through a window with hose in hand to get the water to the fire. A forest fire is different in that it is not so confined and is continually moving. It appears then that to have firemen dismount from the vehicle, unreel hose and walk with the hose in hand to the fire is not the most expeditious method. It seems then that the "off the road" suppression vehicles described above should be equipped with turret mounted remote controlled nozzles so that the driver could actuate the nozzles from his seat in much the same fashion that a gunner fires his guns from a turret.

(d) In order that the driver can maintain his efficiency, performance and clear thinking, it seems important that the vehicle which will be used to fight wild fires be equipped with a pressurized cabin for the assured pure air life support of the operator. He might also be equipped with a cooled suit for comfort, efficiency and safety. It is estimated that the capsule or enclosure for the driver would cost from $7,500 to $10,000 to build, whereas the remotely controlled nozzle could be supplied for $3,000 to $4,000 (Vaughan, 1973).

3. <u>Airborne Quenching Technology</u>

(a) Air tanker fleets are quite effective in helping to quench wildland fires. It appears, however, that two of the remaining difficulties encountered are:

(1) inaccuracy of the drop

(2) improper flow rate during the spread.

In an attempt to improve this performance, FMC carried out a design and development program (Modular Air Fire

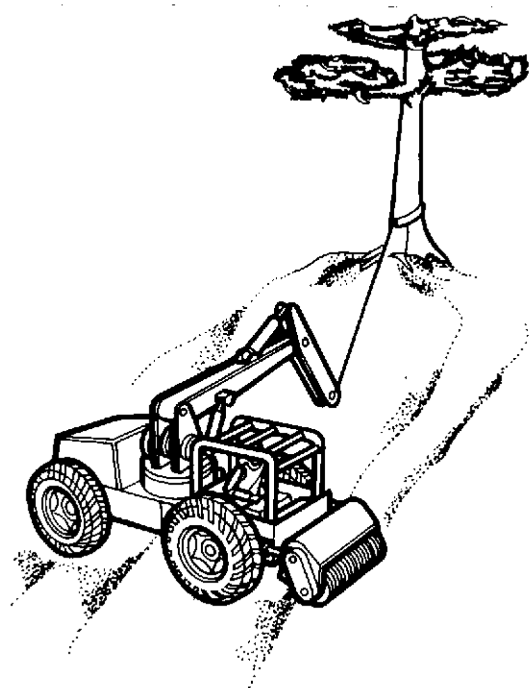


Figure 6.25 Tether Vehicle

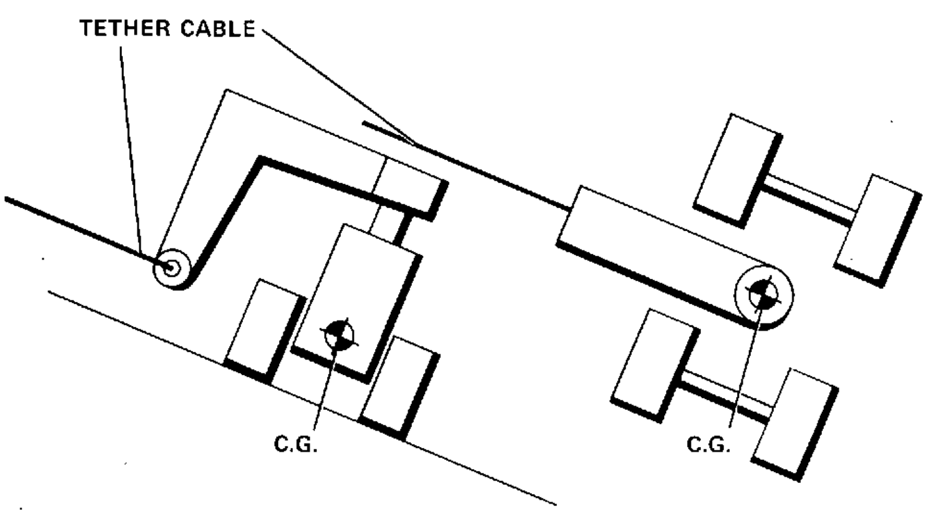


Figure 6.26 Force Diagram

Fighting System, MAFFS) for the Air Force under the guidance of the U.S. Forest Service (Vaughan, 1973), (Figs. 6.27 and 6.28). During the program, many different types of aircraft were flown. The parameters studied included type of retardant, discharge pressure, flow rate, air speed, drop height, and the viscosity of the fluid. The idea of using formation flights of aircraft in dropping long lines of fire retardants to build temporary wide belts of fire lines has not been seriously evaluated (Fig. 6.29). Taking the results of Fig. 6.30, one might hope for results as suggested in Fig. 6.31.

(b) In the area of future investigation, one might consider the use of low order deflagrating explosives to attack the head of a fire. If the use of aircraft were seriously considered for this purpose, then the use of "water bombs" might be investigated--containers of fluid helogens packaged with deflagrating explosives, perhaps. These might be layed on with pin point accuracy with laser or I.R. "smart bomb" technology for spot fires.

(c) The discharge of super cooled granulated ice over the head of the fire as a cooling agent might also be worth investigating inasmuch as the ice has a greater energy absorption capacity than water, and presumably it could fall to the upper portion of the flame before melting, whereas water tends to evaporate at a greater height and be blown away. Since the combustion products of the fire are roughly half water vapor, the use of ice as a seeding agent might also trigger a return of water in the form of rain to help quench the blaze.

(d) Helicopters offer a variety of possibilities. Consider the following:

(1) Use quick action clamps for attaching or detaching an underslung tank of water on the undercarriage. Furthermore, let the tank be equipped with a retractable hose with remotely controlled nozzle. When the craft approaches the target area, the nozzle could be lowered and the water dispensed at optimum rate on the proper areas (Fig. 6.32).

(2) Alternately, let the helicopter tank be supplied by a hose leading from the ground up to the craft. In this case, the water tank could be eliminated, and the vehicle would "carry the hose" which is fed by a pump on the ground. The nozzle would still be controlled remotely as in the preceding case. Really, the only new idea in this suggestion is having water pumped through the hose

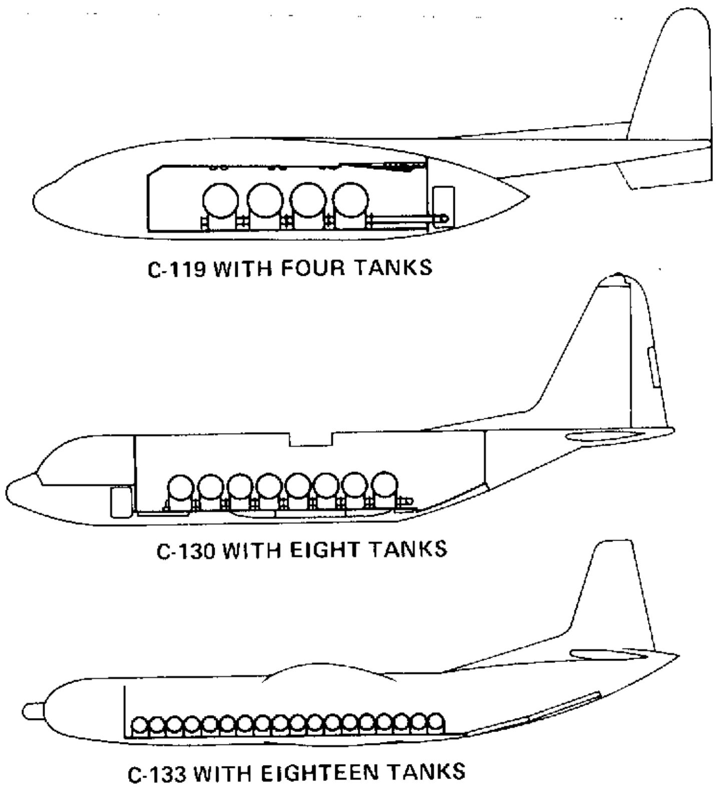


Figure 6.27 Air Tankers MAFFS System

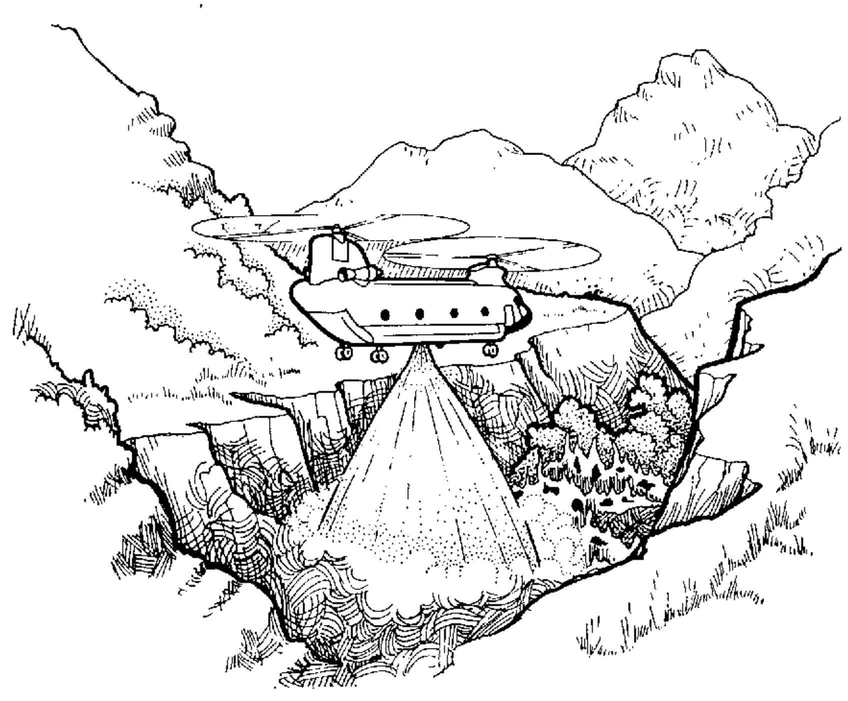


Figure 6.28 Helicopter MAFFS System

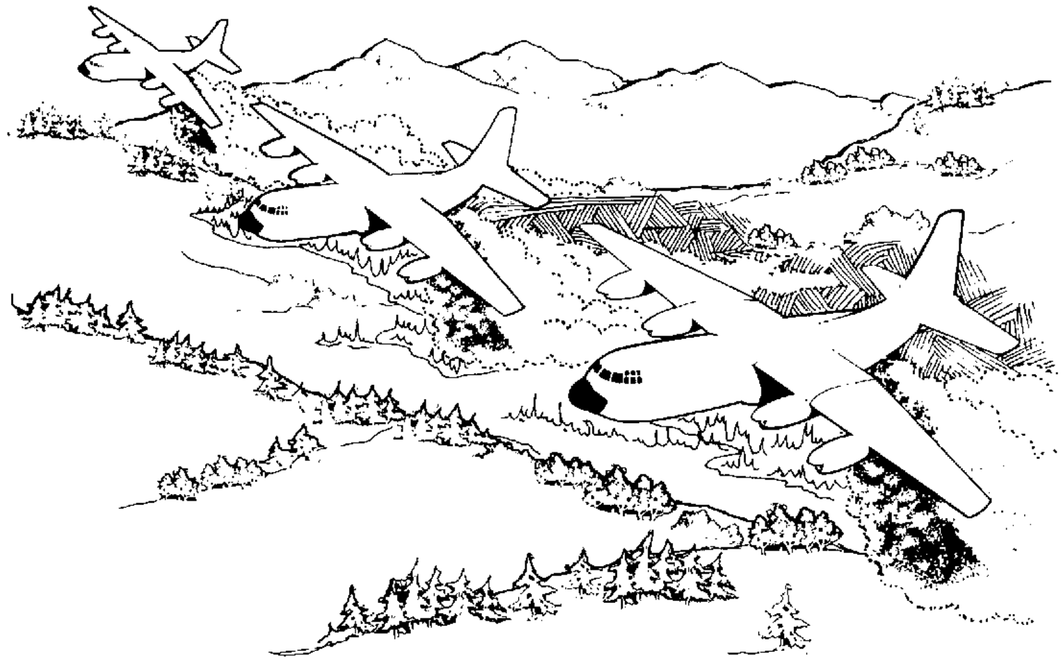


Figure 6.29 Air Tankers — Formation Drop

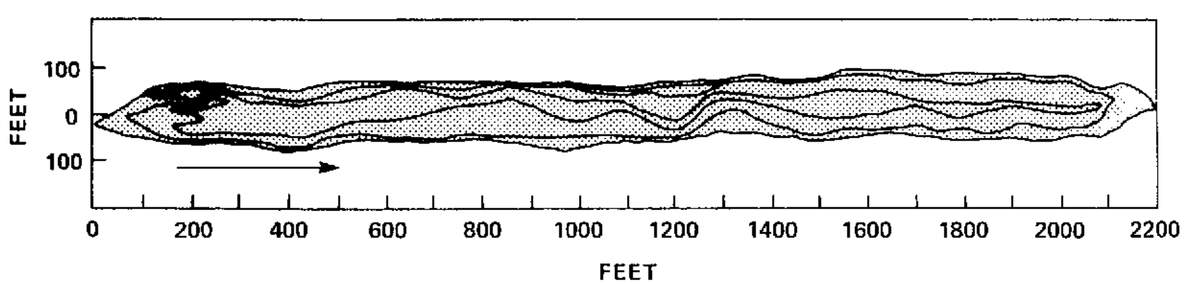


Figure 6.30 MAFFS-Five-Tank Ground Pattern

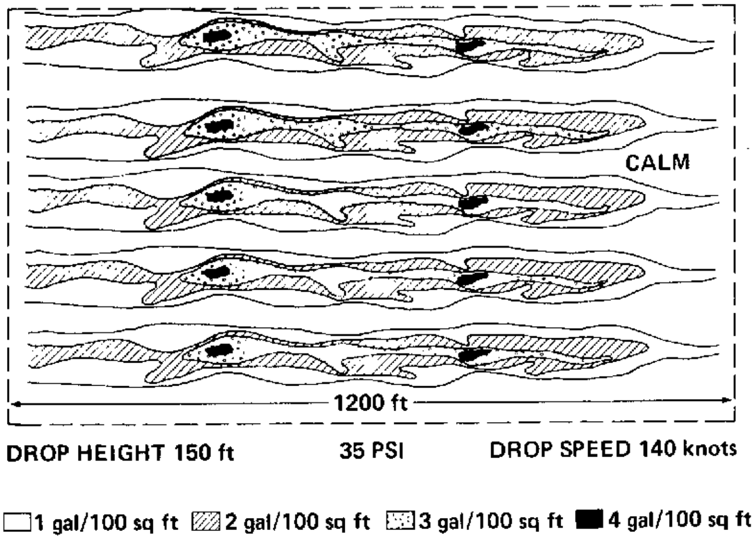


Figure 6.31 Potential MAFFS Formation Drop

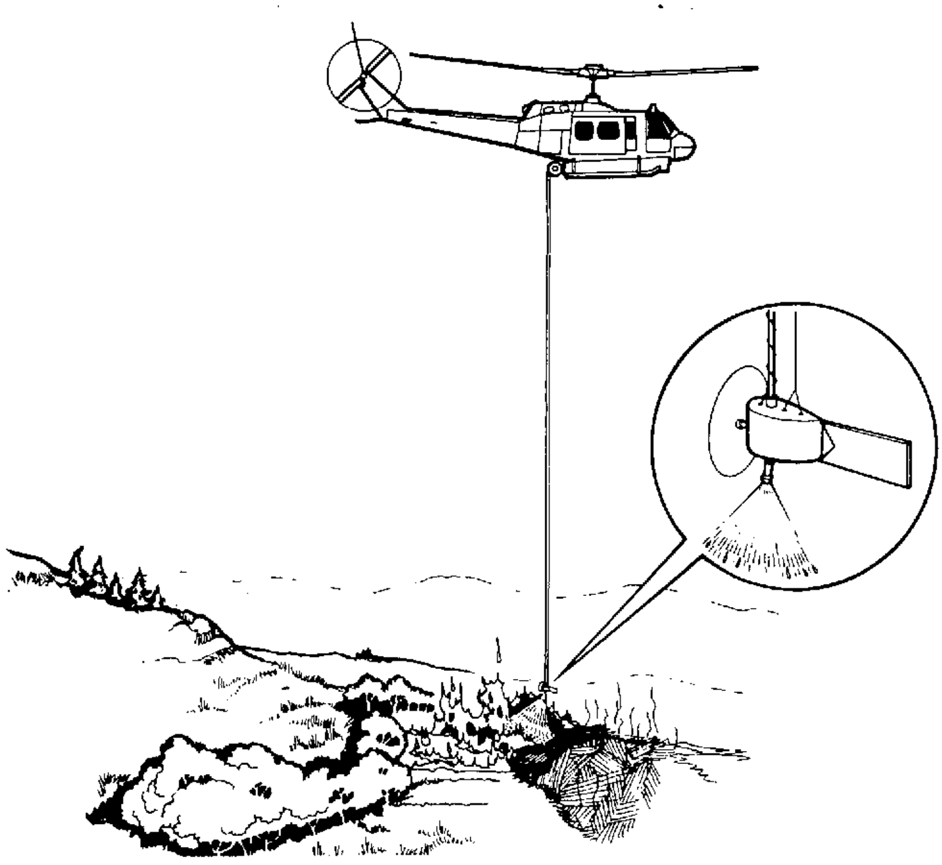


Figure 6.32 Helicopter with Quick Detach (Elements)

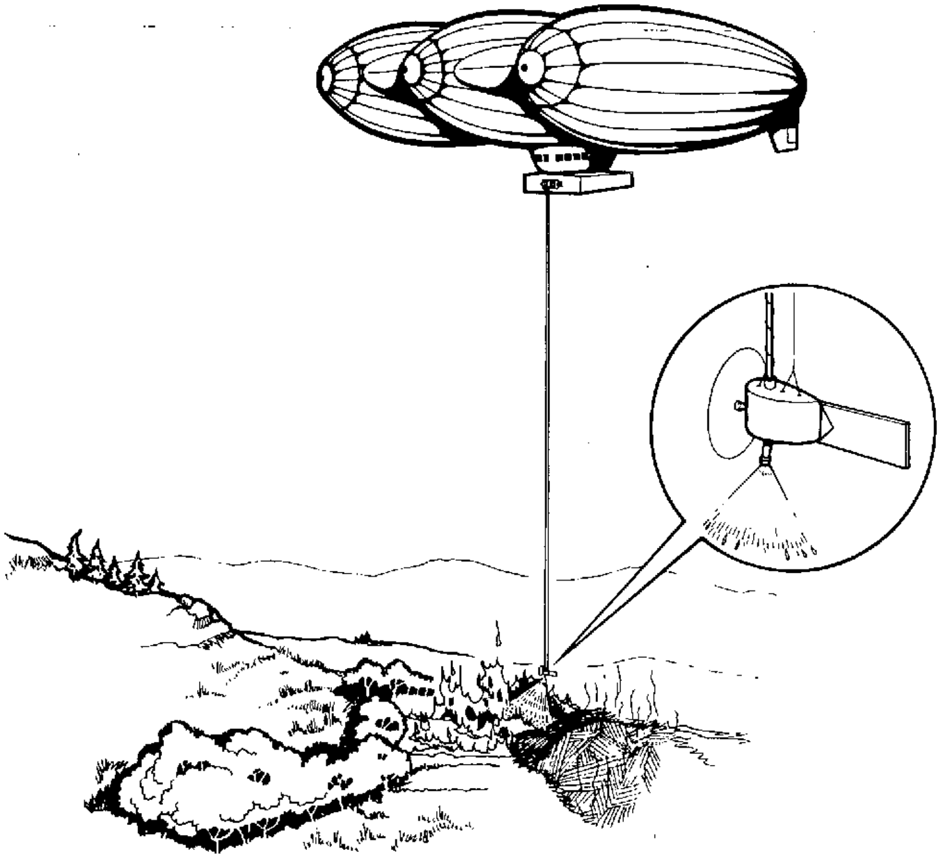
which is suspended from the undercarriage while the nozzle is controlled remotely, because helicopters have already been used for the rapid laying of hose.

(e) Dirigibles are suggested as an air vehicle worthy of further consideration (Havill, 1973). They should be constructed of thin metal skin to prevent damage by sparks from the fire. They can carry rather heavy loads; their horizontal motion is slow, and they can hover. These features would enable night operations (actually 24 hour operation) and hence greatly increase the capability of night quenching. The two procedures suggested for helicopters are also mentioned here for the dirigible--dispensing water via a lowered remotely controlled hose supplied from an on-board tank vs water supply coming up through a hose fed by a pump on the ground (Figs. 6.33 and 6.34).

(f) Goodyear Aerospace Corporation reports (Gerring, 1973) that Goodyear blimps have occasionally flown 6 to 8 hour missions over forests in search for spot fires. These forests had very high fire danger ratings because of long continuous dry spells. It was reported that spotters unanimously agreed that the blimp provided a softer and smoother ride than any other air vehicle. In an aerial spotter mode, the Goodyear blimp can presently stand off upwind from a raging forest fire. It can change altitude readily and run across local winds at 50 knots for 10 hour duty cycles night and day to carry an airship observer who can continuously discern the ground and air situation over the entire scene by eyeball and with infrared instrumentation.

A new design of the currently configured Goodyear blimp would be required for flying at low altitudes immediately downwind or over the fire lines, because of the fire hazards to the fabric in the current airship envelope and the lack of adequate control to handle the winds and thermal air currents at these locations. Goodyear projects that a properly designed airship should be a viable addition to a forest fire fighting force. The skin, gondola, cabin, engines, and control surfaces should be of fireproof design and construction. The necessary features for such an airship have been demonstrated in earlier airship models, but further investigation is required to adopt today's technological advantages for maximum economy, and utility. Goodyear projects the following capabilities for an airship of the above mentioned design (Gerring, op. cit.):

(1) Low, slow, night-time, over-flights with high intensity search lights (and infrared instrumentation) to assist ground fire fighters and to spot access paths to burning areas.



Fiaure 6.33 Multiple Fuselage Airship

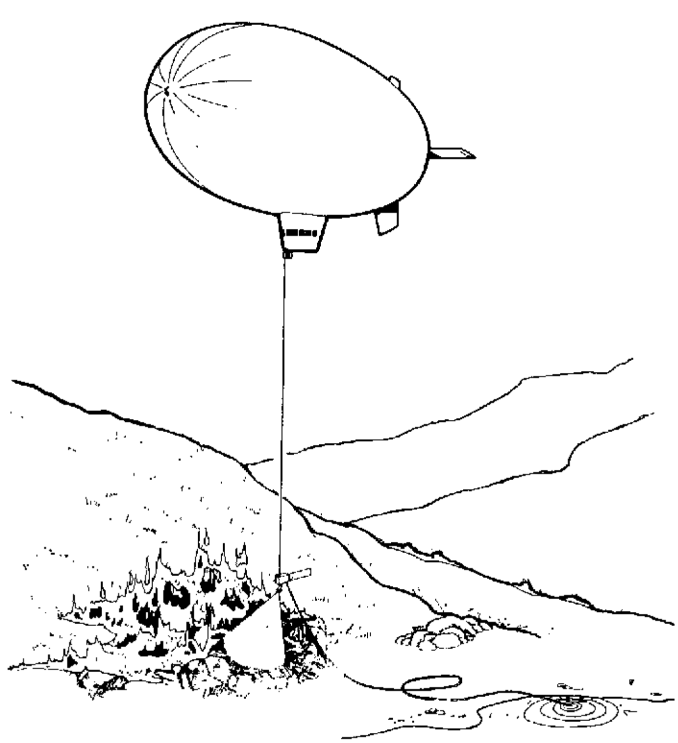


Figure 6.34 Airship with Ground Fed Hose

(2) The carrying of up to 20,000 pounds of water and/or chemicals to spray from low altitude and at slow speed of travel. This payload could be in preloaded canisters picked up at depots or servicing areas by the airship, or the blimp could reload them in flight by pumping lake or stream water aboard as was done in the case of ballast during World War II.

(3) The airship might lift the end of a very long high pressure hose and carry it over the fire as water flowed forth from the nozzle. The hose would be connected to a high pressure high volume pump on the ground, which might be at a lake or stream, or at a mobile ground tanker which could follow the airship and thus increase the radius of effective coverage (Fig. 6.34).

(4) The airship could serve as an airborne command and observation post for directing the activities of the fire fighting establishment.

(5) The airship equipped with infrared detectors could effectively patrol large forest areas continuously during the peak danger periods to detect and locate "hot spots."

(g) Recognizing the concurrent problems of deployment and handling, balloons may offer a means of providing a platform for holding and remotely controlling a ground fed hose. It is noted that balloons are currently being used in logging operations and ship to shore transfer of cargo. It has been reported that tethered balloons can be operated on a day to day basis on such assignments, with modest payloads, in winds up to 50 knots (Young, 1968). The heated air and fire induced component of the wind might add to the stability of a tethered balloon (Stauber, 1973). Since balloons can function at night and, in very poor visibility conditions, they might be adapted to use in mountainous terrain, and hence they offer a potential for fighting fire where other means cannot function. Hot air is used as an alternate to Helium and offers some inherent advantages, cost being only one. Suggested uses for this type of balloon include an airborne observation post to aid in the direction and analysis of fire fighting activities and carrying search lights for night fire fighting (Winker, 1969). It is noted that a one-man, 40 foot, balloon is currently used for inspection of tree tops for diseases and insect infestations. It is also used as a work platform for harvesting pine cones for their seed and to accomplish controlled pollenization (Winker, op. cit.). A 5 ton model balloon costs around $75,000, whereas a 10 ton model would be on the order of $125,000.

It might well be that wild fire mission type balloons should have a skin made of light sheet metal instead of fabric in order to prevent damage by flying sparks.

(h) Experience in balloon technology (Young, 1968) has shown that the spherical shape left something to be desired aerodynamically. Some efforts to correct this are seen in the Drachen and Caquot balloons (Fig. 6.36). Today, the four main types of tethered balloons in use are:

(1) the sphere

(2) the natural shape (Fig. 6.33)

(3) the single hull (Fig. 6.38)

(4) the vee

Should a balloon be used as a piece of fire suppression equipment, it is recommended for regions where a tri-tether system would be feasible. Using this idea, a balloon drenching system is illustrated in Fig. 6.35. Each of the anchors for the three tethers might be a piece of heavy mobile equipment suitable for off the road operations in 60% slope, 30% side slope. The main tether cable could also serve as an aerial tramway line to and from the balloon. A ground fed drenching supply hose could be suspended from the balloon, and actuation of the three winches (one at each anchor point) could continuously reposition the array supported by the balloon along the fire line. A gondola containing a water drenching nozzle might be suspended far below the balloon, powered, and remotely controlled. In this manner, the remotely controlled drenching nozzle could be moved small amounts relative to the balloon as required. Hence, the following controlled movement of the nozzle might be possible:

(1) motion of the remotely controlled nozzle with respect to the gondola

(2) motion of the powered gondola relative to the balloon

(3) motion of the balloon relative to the three anchor points via the winches

(4) motion of the three anchor points since they are each a large piece of heavy ground equipment

Assuming a $75,000 balloon, a $60,000 dragon wagon tanker, two $40,000 caterpillar tractors, and $30,000 in hanlding hardware, pumps, winches, etc., such a drenching system at $245,000 compares to the cost of a light helicopter.

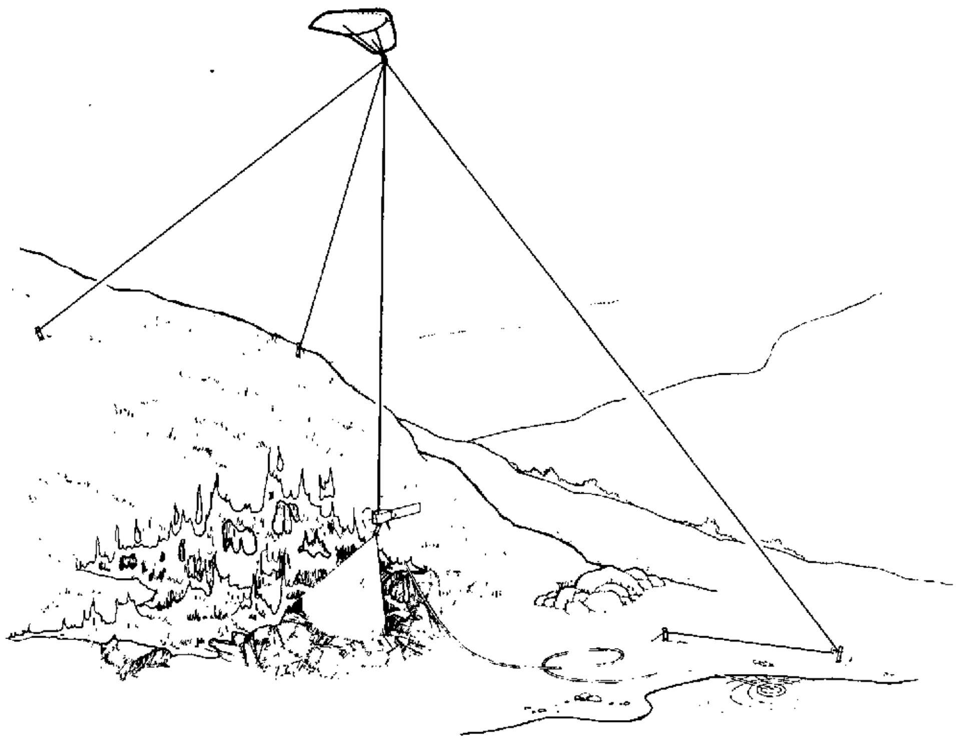


Figure 6.35 Balloon Tether System with Hose

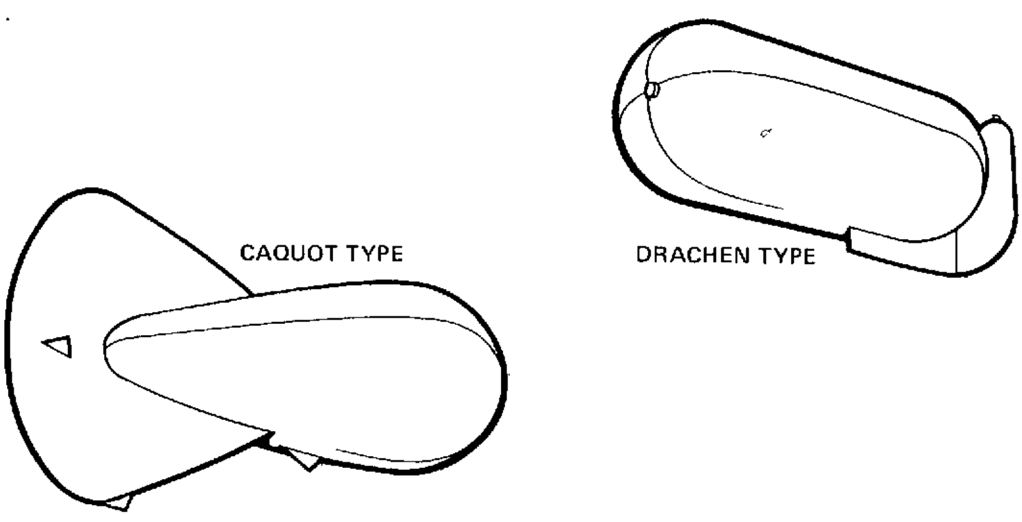


Figure 6.36 Balloon, CAQUOT–DRACHEN

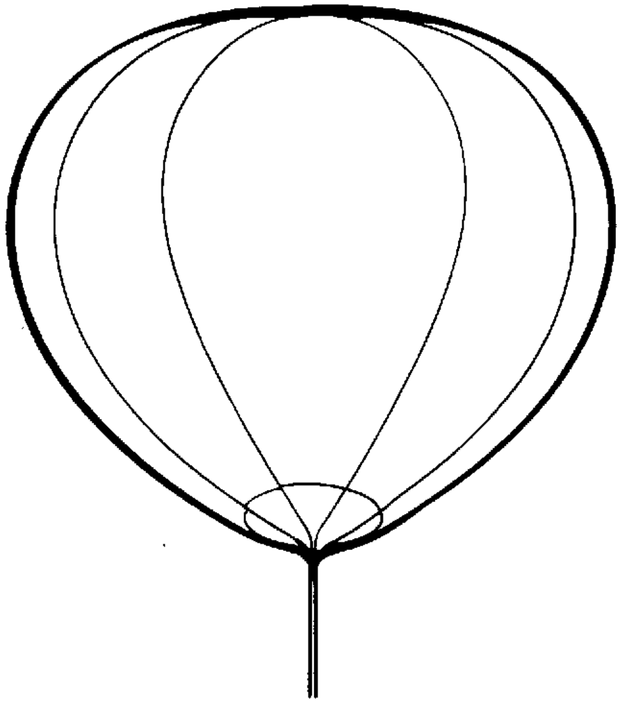


Figure 6.37 Balloon, Naturally Shaped

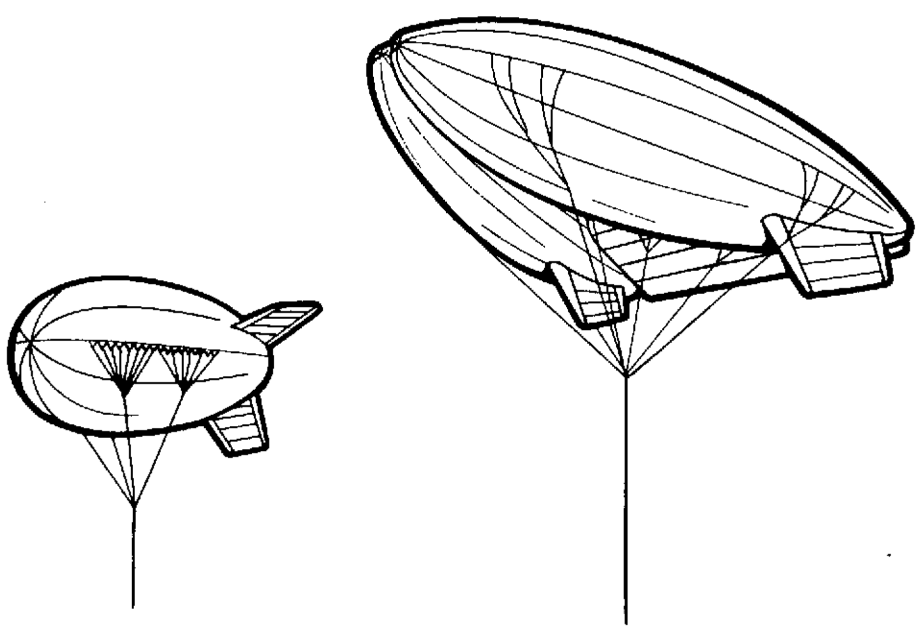


Figure 6.38 Single Hull and Vee Types

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Chapter VII

THE SAFETY OF THE INDIVIDUAL FIRE FIGHTER

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Chapter VII

THE SAFETY OF THE INDIVIDUAL FIRE FIGHTER

A. Introduction

The safety of the individual fire fighter is of primary concern during every fire suppression activity. The major safety requirement for any fire fighter is a thorough knowledge and respect for the fire. The thrust of this work on safety will be to allow the individual to escape from or through the fire in the event of being trapped. The major areas of concern are the protection of the head and respiratory system; body; and the implementation of training.

B. Protection from Fire of the Head and Respiratory System

Heat and intelligence are the primary safety factors. Perceived heat serves as an indication that one is too close to the fire, and basic intelligence to move to a safer working area is mandatory. However, there will always be occasions when the person is trapped and his escape alternatives are either through the fire or allow the fire to pass over him. In these cases, the protection of the head and respiratory system is imperative.

1. Hoods

At the present time, an individual "fire tent" is standard equipment. It is believed that this is not optimum, since it does not allow the person to view the fire and make an escape. A passive hood system for the head with other clothing for the body would be preferred. A polymide hood has been developed for aircraft fires which could be an alternative. There have been studies (E. B. McFadden) which examine this particular hood for:

(a) protection against smoke and toxic gases

(b) protection from fire

(c) any limitations of the hood in

  (1) air supply
  (2) vision
  (3) hearing

2. Temporary Life Support Supplies

It is assumed that the continuous supply or rebreather gas masks developed by 1985 will still have serious limitations due to weight (15 to 20 pounds), visibility obstruction and leakage. Therefore, a hood design is recommended which will fit over the entire head with an elastic polyurethane seal at the neck. This will protect the person from toxic gases, smoke, or inhaling flames.

The length of protection is dependent upon the size of the hood. In one previously tested (18.5L) the oxygen supply and carbon dioxide levels were chosen for the threshold of psychomotor efficiency, and it was found that under exercise and increased temperature, a level of 8% CO_2 was reached in a mean time of 2.2 minutes (McFadden, 1970). This could be increased or decreased upon the need in our case.

A similar hood was tested for protection from convective and radiant heat. It was constructed of "Kapton" which is a high temperature polymide film. It does not begin to char until temperatures exceed 1472°F. With mean temperatures of 145°F, the forehead temperature, after 8 minutes, was less than 100°F. The major reason for termination of the tests was the decrease in oxygen supply. It has also been shown that the hood has no appreciable acoustic attenuation and transmits approximately 75 to 80% of the ambient light (Allen, 1969).

C. Fire Protective Clothing

The development of the Nomex shirt protected the individual from flying embers and provided some protection from direct flame. The two areas of concern, in this report, will be the body exposure due to a conventional shirt construction and the lack of prolonged protection (up to 2 minutes) from direct flames.

The exposure of the body under the shirt and hands may be alleviated by designing the shirts with "button under" devices or a one piece shirt-pants design. The design of light weight fire resistant gloves has not fully been explored as of 1973.

There are two basic types of suits for flame protection. The first is a heavy ventilated fire resistant material and the second is a foam suit system. The foam system provides a rapid nonflammable atmosphere between the body and the outer garment. Foam is dispersed throughout the suit by a series of small tubes fed by a pressurized canister.

A commercially available system in 1973 has been tested with the initial foaming action lasting for 30 seconds with residual foam for 3 minutes. This "Foam Deluge System" is available from ILC Industries.

This type of foam deluge suit made of an advanced "Nomex" type material will be available by 1985. A comparison of commercial and experimental fabric characterization is given in Table 7.1. It is readily seen that there are experimental materials with less weight, better wear resistance, and an order of magnitude better in thermal conductivity than those commercially available. It is assumed that these, or other, materials will be available by 1985.

A sketch of the fire protective material with a foam suit and hood is given in Fig. 7.1. The top of the hood is aluminized to enhance the reflectance of the radiant heat without obstructing visibility.

Table 7.1

COMPARISON OF COMMERCIAL AND EXPERIMENTAL FABRIC CHARACTERIZATION

Fabric	Weight oz/yd^2	Wear Resistance No. Cycles	Stiffness in/lb	Thermal Conductivity (°C/cm)	Availability (1973)	Supplier
Nylon	6.9	174	0.002	1.49×10^{-4}	Commercial	Stern Stern
Beta	6.5	148	0.003	1.69×10^{-4}	Commerical	Owens Corning
Beta	6.1	151	0.003	1.2×10^{-4}	Special Order	Owens Corning
Nomex	6.2	689	0.001	1.58×10^{-4}	Commercial	Stern Stern
Nomex	7.3	353	0.004	1.6×10^{-4}	Experimental	Dynatec Dynatec
Polybenzimidazene (untreated)	5.0	206	0.004	3×10^{-5}	Government Use Only	Celanese Celanese
Polybenzimidazene (treated)	5.9	721	0.002	4.8×10^{-5}	Experimental	Monsanto Monsanto
Polybenzimidazene	8.0	234	0.002	3.2×10^{-5}	Experimental	Dynatec Dynatec

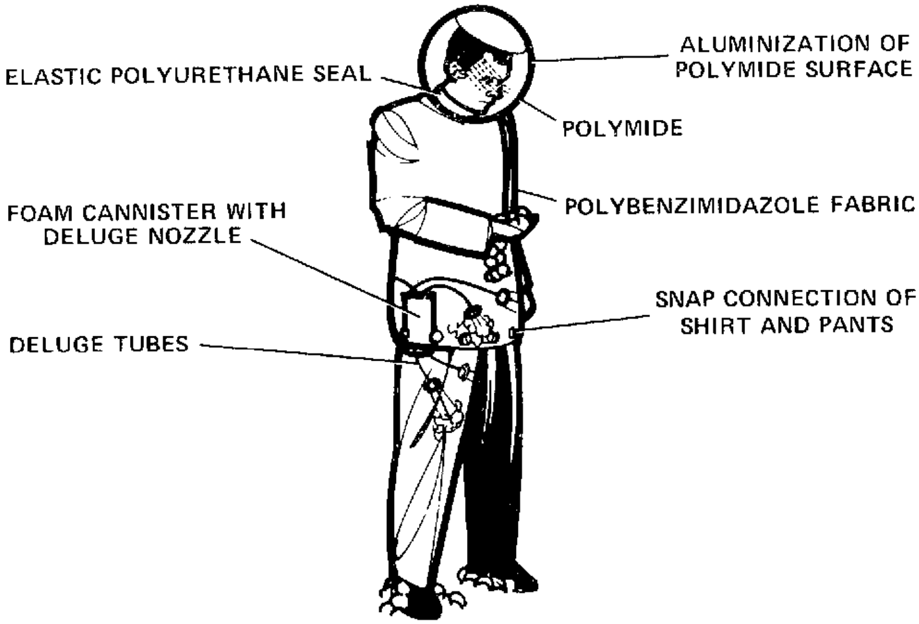

Figure 7.1 Fire Protective Suit

D. Safety of the Vehicle Driver

The philosophy in this chapter for the safety of the individual fire fighter has been to allow him to "escape." There has been no attempt to mechanically keep him out of a potentially hazardous condition. It is believed more feasible, with vehicle drivers, to initially create a situation for predanger decision making, and then facilitate escape from these dangers by driving or walking out should they occur.

1. Tolerance Limits

Extended exposure to high temperature causes physiological and psychological deterioration in human performance. The handbook for "Human Engineering Data" states the physiological tolerances of man as shown in Fig. 7.2. For the fire environment of 120°F and 10% RH, the tolerance limit is 4 hours. There is also some deterioration (although quantitatively disputed) in the manual dexterity, vigilance, and reaction time of people in a "hot" environment. There is no dispute on the amount of manual labor ability deterioration under high temperature conditions (J. A. Vaughan, J. D. Hardy, J. J. Sullivan).

2. Head Cooling

It has been shown by many people (A. Chambers, E. Schwartz, S. A. Nunneley) that water-cooled garments effectively control the skin temperature and keep the individual in the "comfort zone." It has also been shown (B. Williams) that "head cooling" can be very effective by itself. Results show that there is a decrease of 76% in heart rate rise during exposure to 115°F over uncooled exposure, and also a decrease in rectal temperature rise of 60% over the normal rectal temperature rise at 115°F. There was also a 50% less sweat weight loss than normal sweat weight loss at these temperatures with head cooling. Such cooling has been used on race car drivers (R. Petty) with much subjective success.

A temperature controlled head gear for cooling of the neck/ head area would allow the driver to work effectively in the 1985-1995 vehicles. These vehicles will probably work closer to the fire for longer periods of time, and thus the maintenance of an alert driver is mandatory. A sketch of the head cooling gear is shown in Fig. 7.3.

E. Training

The abuse of new safety devices may make the individual more susceptible to inserting himself into a dangerous situation. That is, if he feels he can "walk out," he may be more susceptible to "walk in." It must be impressed upon the individual that these proposed safety devices are not to allow him to more effectively fight a fire. He must also be trained to effectively use them. This will take the form of lectures and actual demonstration of the devices under fire conditions.

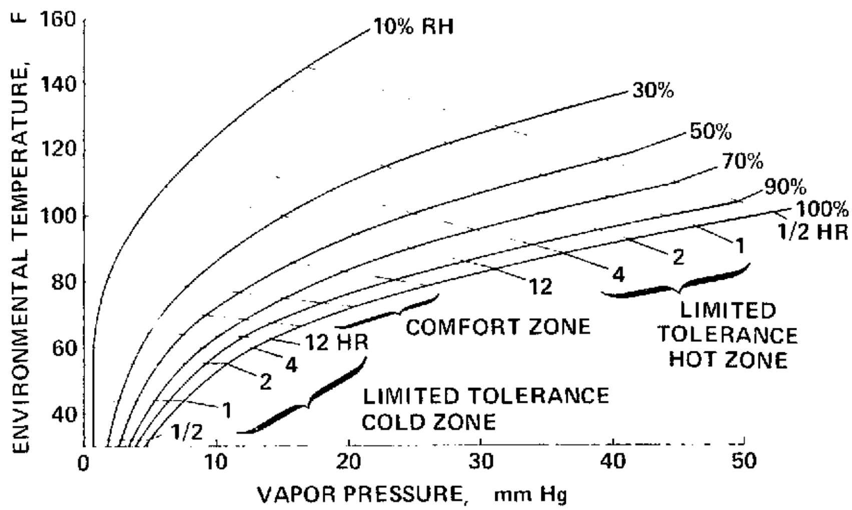

Figure 7.2 Tolerance-Comfort Limits, Temperature/Humidity

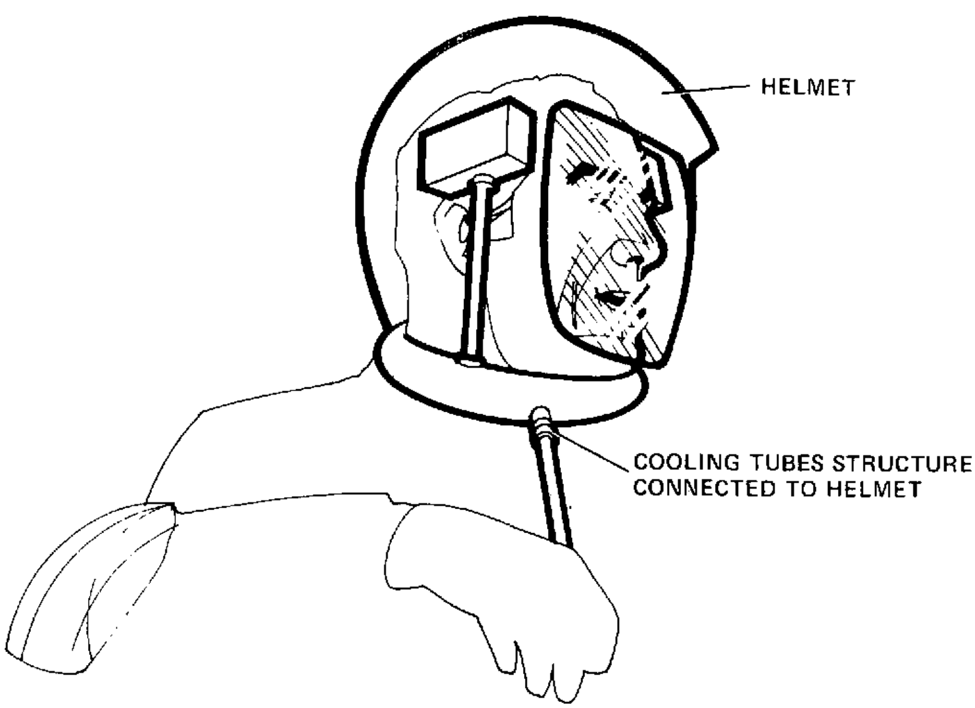

Figure 7.3 Temperature Control Helmet

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Chapter VIII

OVERALL SYSTEMS FUNCTION

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Chapter VIII

OVERALL SYSTEM FUNCTION

A. Information and Decision Flow

The overall system information flow within the system is illustrated in Fig. 8.1, where

S = Sensors

DIC = Digital Information Channel

DINC = Digital Interrogation Channel

V = Voice Channel

T = Tactics

R = Results

The system of asynchronous satellites with multispectral sensors produces a wide (3000 nautical mile) ground image. It is digitalized and sent to the synchronous satellite. This satellite then transmits the image to a National Control Center. The Control Center with an Illiac type computer stores the information and processes the data as determined by the interrogation units from the Primary Wildland Center. The Control Center may in turn interrogate the satellite system for specific information on a small area (10 miles square) basis.

The Primary Wildland Management Center receives the large scale scan with "flags" for fires detected. This is sent digitally to the Regional Fire Center whose data output is an image with "flags." California's portion of this image information is sent to the California State Center (CSCC).

The CSCC processes the information into data for passive prevention and active suppression operations. For real time suppression operations, this processing includes generation of fire locations, fire mapping, suppression force status, and fire status for each such instance in California. The passive or longer time interval prevention data processing includes time and location schedules for prescribed burning, fuel status, and surveillance of possible infringements of fire control laws such as burning permits, fire codes, and land use, based on localized FDR's (Fire Danger Rating).

The system function as it applies to fire detection and suppression, prescribed burning, wildland structures, seeding, planting, and the assignment of local FDR is described in Figs. 8.2 to 8.6.

The primary function of the California State Command Center is to accept the ground multispectral images and remote weather station data of the California Wildlands and process the information into the following areas:

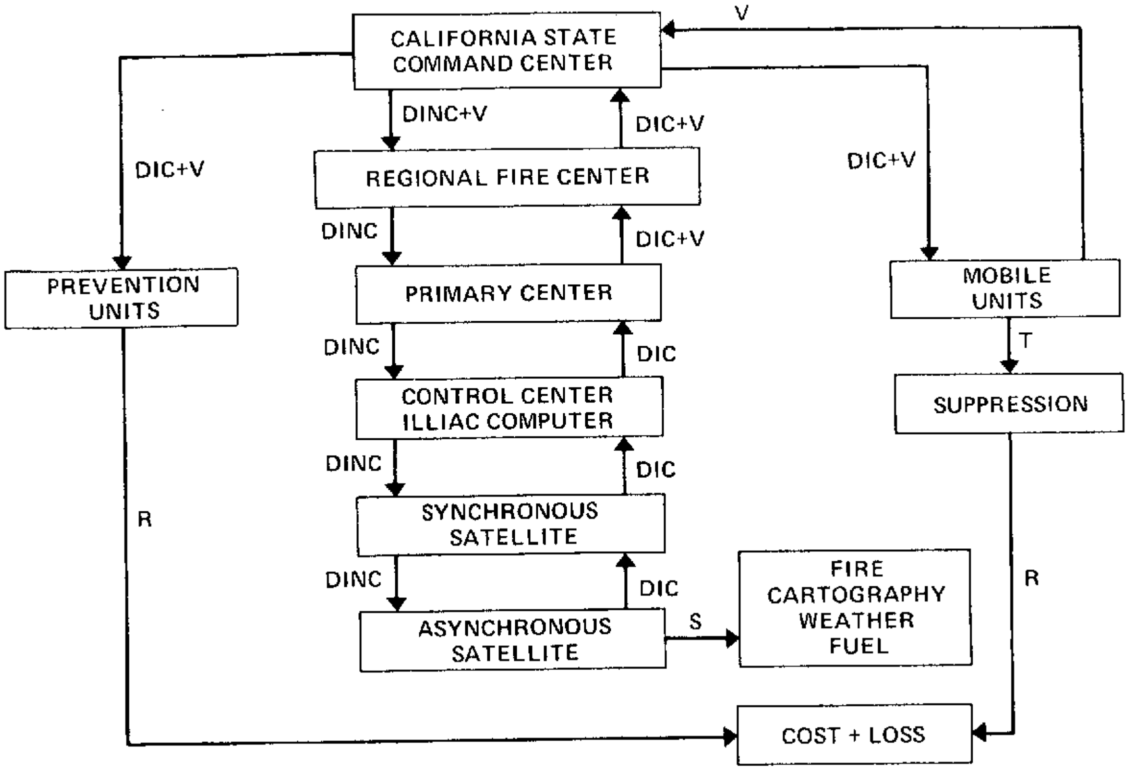

Figure 8.1 Basic Decision Flow Diagram

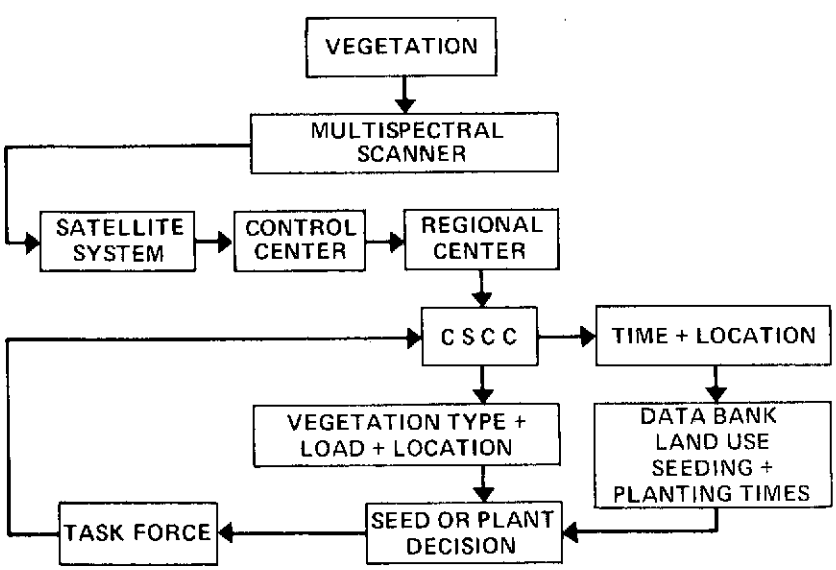

Figure 8.2 Information Flow for Seeding and Planting

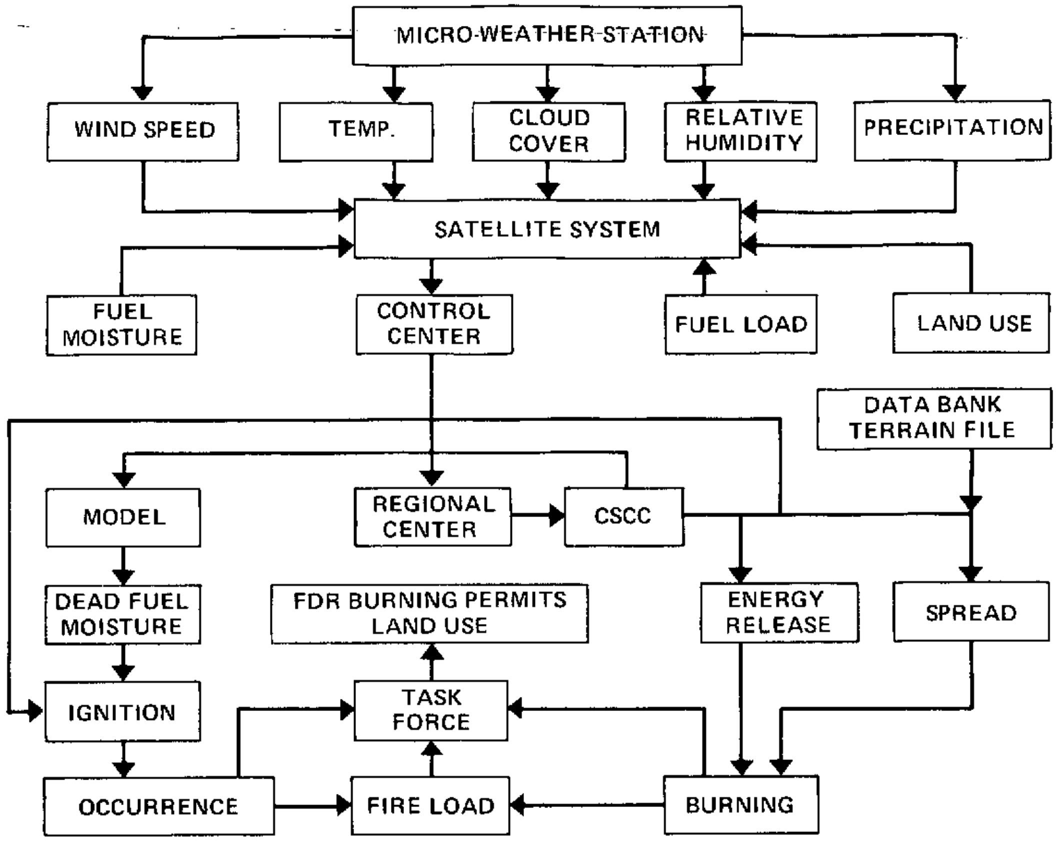

Figure 8.3 Information Flow for Burning Permits, Land Use

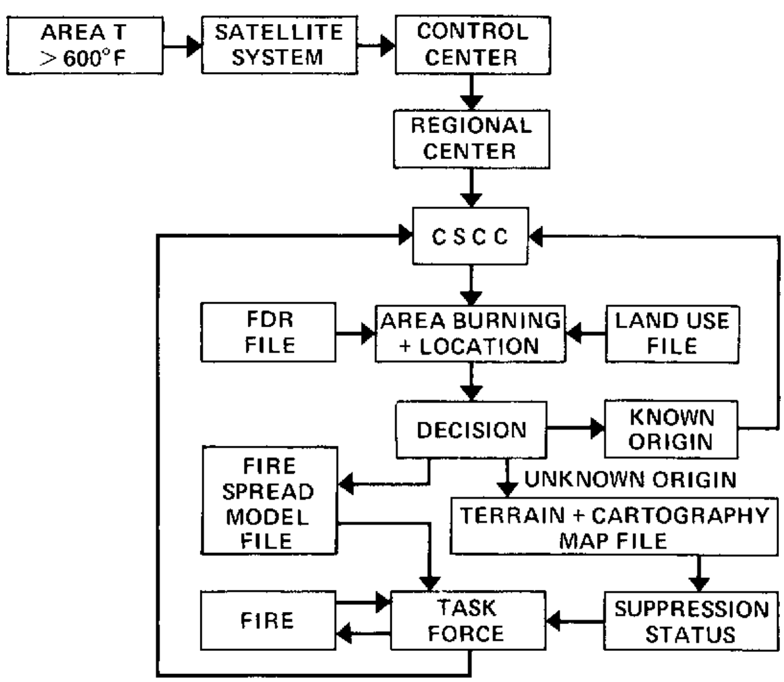

Figure 8.4 Information Flow for Initial Attack Suppression

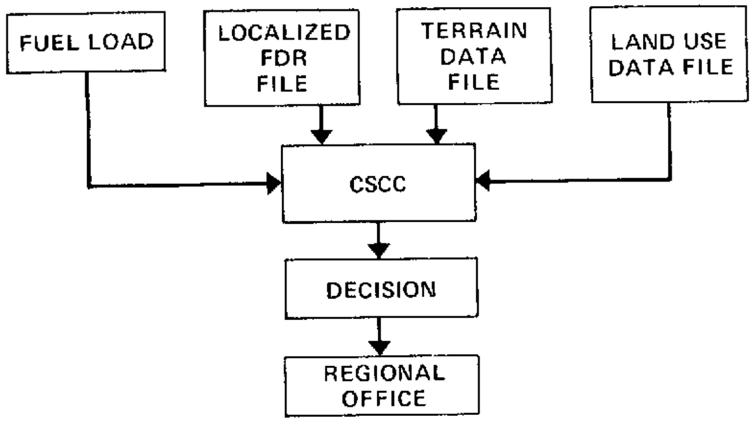

Figure 8.5 Information Flow for Prescribed Burning

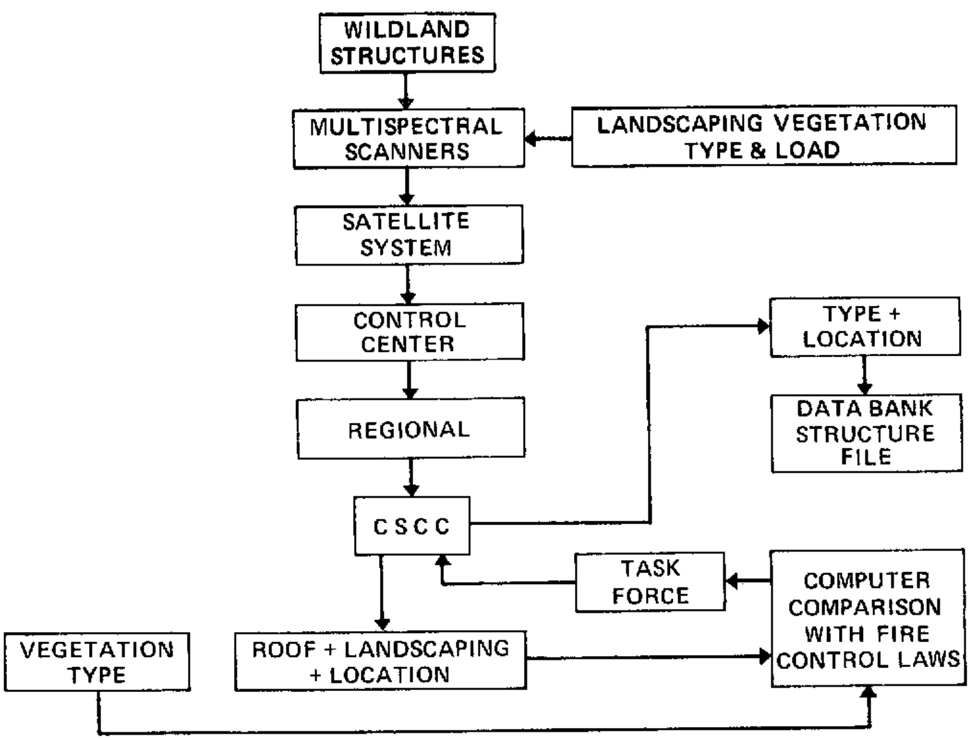

Figure 8.6 Information Flow for Wildland Structures

a. unknown fire

b. interpolation of micro-weather

c. micro-area FDR

d. variations in land use

e. variations in vegetation vigor

f. variations in vegetation type

This information is then fed into the specific California computer files for updating the decision analysis.

Date filed by other California remote collection and processing channels or nonreal-time processing are:

a. terrain mapping

b. cartography

c. agricultural information

d. fire history by location

e. suppression status

This information is processed, filtered, and coupled in California with data received from the regional centers with State decision algorithms on specific actions. This enables the regional office to initiate a quick response to any pertinent wild fire decision whether it be prevention activities or suppression tactics. The function of the communication system is to facilitate the various tasks and reports involved in an initial attack, reinforced attack, and regional attack on a wildland fire. A block diagram of the communication chain is given in Fig. 8.7 where

T = Task designation

R = Report of progress

The communication links for this operation is given in Table 8.1.

B. The Modular Task Force Function

The problem of phasing in various suppression forces to a growing wild fire perimeter has a number of ramifications:

(a) Access--the direct ground approaches; available highway, road trails, bush, terrain, and obstructions for off the road operations.

(b) Visibility--day or night operations - a function of the time of the event.

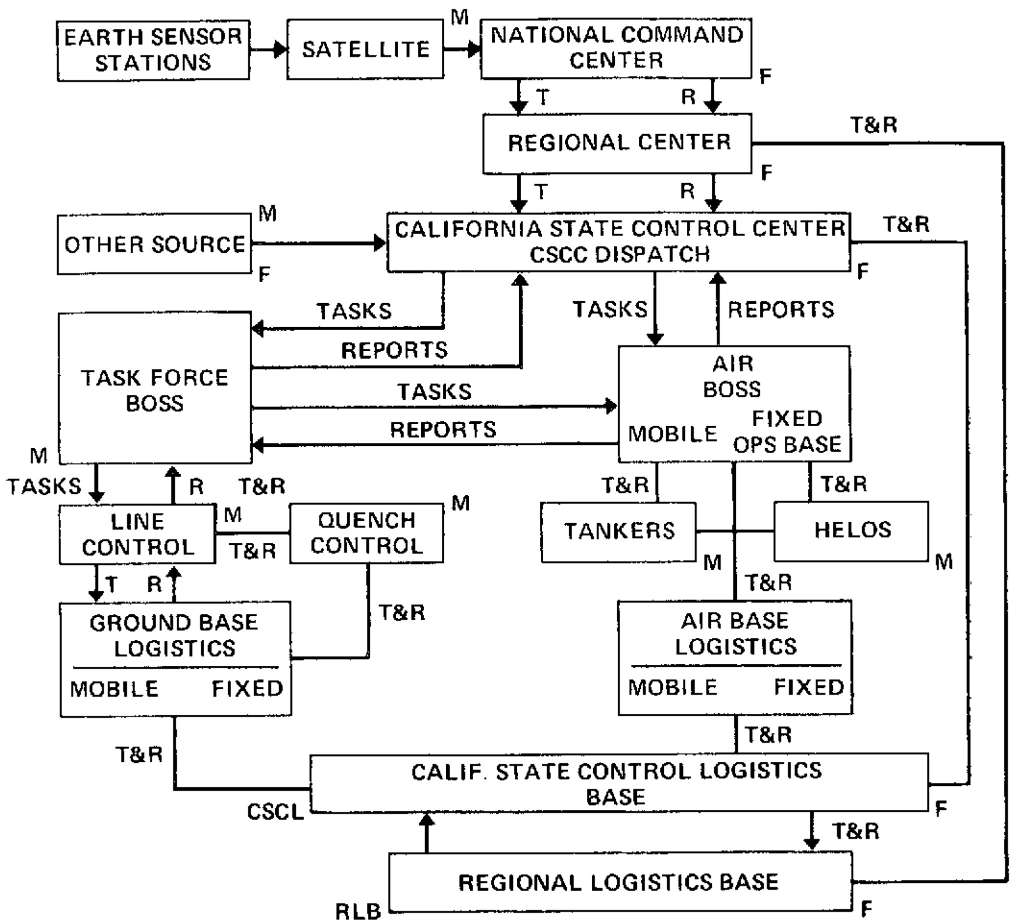

Figure 8.7 Communications for Task Force Operations

Table 8.1

COMMUNICATIONS LINKS

LINK ANALYSIS	MODE
EARTH SENSORS TO SATELLITE	DIGITAL BROADCAST DATA LINK
SATELLITE TO NATIONAL CENTER	DIGITAL BROADCAST, ALL DATA
NATIONAL CENTER TO REGIONAL AND BACK	VOICE TELEPHONE DIGITAL HARD WIRE, PARTIAL DATA
REGIONAL TO CSCC AND BACK	FACSIMILE REQUIRED
CSCC TO TASK FORCE BOSS (MOBILE) COMMAND NET	DIGITAL BROADCAST PARTIAL DATA VOICE BROADCAST FACSIMILE REQUIRED TV REQUIRED? / TELETYPE?
TASK FORCE BOSS TO CSCC GROUND COMMAND NET	VOICE BROADCAST TV REQUIRED? / TELETYPE?
CSCC TO AIR BOSS (MOBILE) AIR COMMAND NET	VOICE BROADCAST
TFB TO AB AND BACK TACTICAL AIR NET	VOICE BROADCAST
TFB, LINE CONTROL, QUENCH CONTROL, MOBILE LOGISTICS SECTIONS GROUND TACTICAL NET	VOICE BROADCAST ±
LINE CONTROL, QUENCH CONTROL, MOBILE LOGISTICS EARTH APPARATUS TO SATELLITE	DIGITAL BROADCAST DATA LINK
GROUND LOGISTICS FIXED TO CALIFORNIA STATE CONTROL LOGISTICS	VOICE TELEPHONE DIGITAL HARDWIRE
AB, TANKERS, HELOS, AIR LOGISTICS TACTICAL AIR NET. MOBILE UNITS	VOICE BROADCAST
AIR LOGISTICS TO GROUND LOGISTICS AND BACK (FIXED STATION) CALIFORNIA STATE CONTROL LOGISTICS FIXED STATION	VOICE TELEPHONE DIGITAL HARDWIRE TELETYPE

(c) Spotting Growth and Pocketing--a function of fuel and weather.

(d) Forces Available--line building capability in given terrain.

A computer can keep track of all of these considerations in dispatching the attack forces and in reinforcing the initial forces deployed. The decision on where to build line will be computer aided through predictive fire mapping. The tactics of quenching are largely a matter of on the scene individual judgement. The modular task force in conjunction with a quasi-real time information processing system should be more capable in locating sensitive areas of the fire perimeter for quenching and determining the optimum location of fire breaks.

If we move from a passive state of readiness through an initial attack operation and then into an extended attack series of phases, we can improve our suppression capability by reducing the response time to move between phases. The organizational changes proposed were given in Chapter V while the operational functional units are given in this chapter.

The organizational changes have been made to optimally carry out the following operational requirements of suppression doctrine:

(1) There is one CSCC located in Sacramento probably, and that there is a communications link to the tactical task force commanders that is reliable, and capable of defining specific tasks for each task force commander. Each TFC is given specific sector tasks in a suppression effort, and his territory allocation is explicitly known to his flanking TFC.

(2) All of the elements of the task force (ground) are mobile units. They have the capability of sustained (72 hour) operations in the field prior to relief.

(3) The air boss works directly with, but not for, the task force commander. This means that CSCC can recall or redesignate higher priority tasks for an air boss that take away air services from a task force (ground) commander.

(4) The "home port" logistics base for the task force has primary replenishment capability to support its force by means of mobile shuttle units. These units operate as a component "Service Force" and are a part of the task force tactical organization. When the task force commander is assigned by CSCC outside of his ordinary home base region, his "Service Force" units are deployed with the task force as his mobile logistics unit. The service force boss will provide all replenishment to his task force when deployed by managing his own shuttle operations.

(5) The "home port" logistics bases become the primary resupply points for "visiting firemen" and establish the rest and reserve areas for Task Forces off the line.

(6) The Task Force Commander will establish his own "Spike Camp" at the scene of the fire, and his service force unit boss will provide logistic support for sleeping, food, sanitation, and first aid or air evacuation.

(7) Alert and readiness response times will match the computer fire danger rating system. Response times with assignments are given in Chapter V.

(8) If the CSCC computer fire spread rate prediction or the initial attack boss indicates that the first allocation of resources from a given home base will be insufficient, then reinforcements are dispatched by CSCC to meet the fire spread requirements indicated.

(9) A major computer aided decision to be made determines the forces allocated to "structural protection." The identification of missions to particular forces for "structural protection" activities, based upon fire boundary predictions is an inherent portion of the dispatching function from the CSCC.

(10) In general, the concept of the division within the task force is that within one hour of arrival, the division will be capable of building 1000 yards of line or quenching the perimeters of a fire at an expenditure rate of liquids of 100 gal/min steady for two hours up to replenishment at the start of the second hour. This application rate can be increased by local decision, of course, but first strike replenishments will start at plus 90 minutes, minimum, from service task force truck.

(11) Line clearance operations will depend on the terrain, but in general Tanker Cruisers will have a light dozer blade capability, hand crews will have individual special devices capability for both clearing and quenching, and heavy dozers will be employed where feasible.

(12) Emphasis will be placed by second line older equipment during ground operations on structural protection (on the assumption that greater coverage of homes and property will be required). The current 1973 inventory of fire trucks will be used more and more as time passes for the structural protection mission, while the task of off the road suppression will be allocated more and more toward the special vehicles in 1985.

Chapter IX

COST AND SCHEDULE ANALYSIS

LIST OF FIGURES

Chapter IX

COST AND SCHEDULE ANALYSIS

A. Method of Procedure

The cost study has been separated into four separate but related areas. These areas are:

SATELLITE SYSTEM	includes ground and flight systems at the national and regional levels.
COMMAND AND CONTROL	includes the California State Command and Control installation, along with the 100 mobile vans which serve as movile Task Force Command and Control headquarters (and all communication equipment).
SUPPRESSION OPERATIONS	includes equipment needed by the task force units to fight the fire. It includes both air and ground hardware.
LOGISTICS	includes the bases needed to supply both ground and air suppression activity, as well as the expendable inventory required for maintenance and operations.

The procedure for the first item above is to establish the order of magnitude of the national federal budget problem that is to be solved and justified in order to support a satellite surveillance capability meeting the technical premises of the study. A modified PERT (Program Evaluation and Review Technique) has been used in the process.

1. Satellite System Costs and Program Scheduling

(a) Flight system costs (see Fig. 9.1)

Milestones and Events

(S)* Start 1973 (assumption)

(A) Establishment of Management Authority

(1) Design of Management System

*The circles correspond to similar circles on the PERT diagrams.

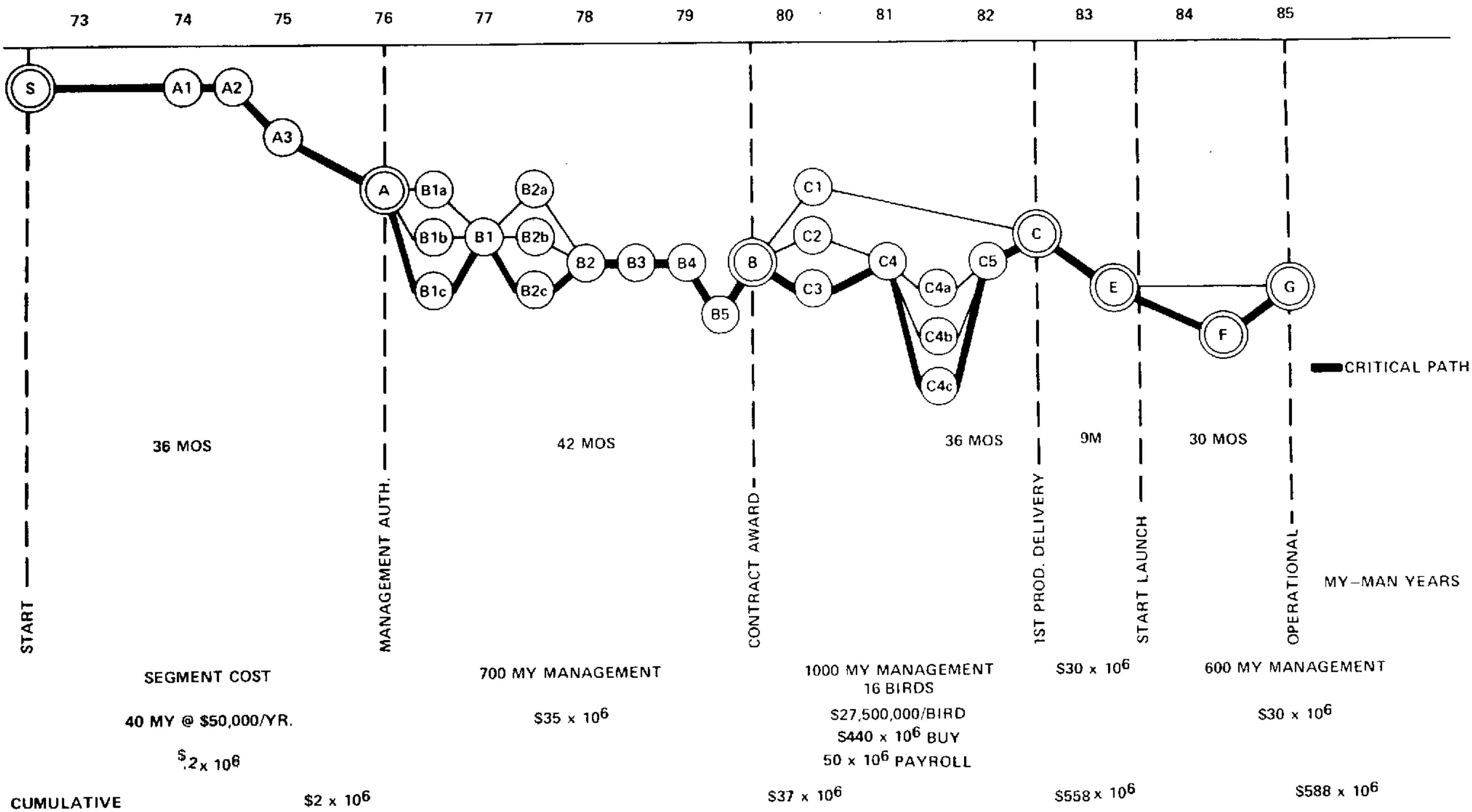

Figure 9.1 Simplified Pert for Satellite Flight System

(2) Legislative Authority

(3) Funding Authority

(B) Satellite Systems Preproduction

(1) Engineering Feasibility Study

(a) Flight Hardware (rocket) *NASA/USAF

(b) Launch Hardware (base) *NASA/USAF

(c) Sensor Package (payload)

(2) Systems Design (Contract Specifications and Drawings)

(a) Sensor Elements Definitive and Configuration

(b) Reliability and Redundancy Study

(c) Quality Assurance Plan

(3) Bid Request

(4) Bid Evaluation

(5) Contract Award

(C) Satellite Production (Fabrication and Assembly)

(1) Propulsion Elements Interface

(2) Sensor Elements

(3) Data Process Elements

(4) Assembly Sensor Payload Package

(a) Interface Problems

(b) Power Supply

(c) Preflight Tests

(5) Mating at Launch Site

(E) Satellite Systems Launch and Flight Control

(1) Polar Bird Launch Schedule

(2) Synchronous Bird Launch Schedule

(F) Start Satellite/Ground Systems Tests

(G) Flight System Operational

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*USAF facilities are required to launch polar orbit.

FISCAL ESTIMATES* SATELLITE SYSTEM

$ × 106 in FY 1973 Dollars

Year	Government Payroll	Vendor Contract (Buy Items)
1973	0.5	
1974	0.5	
1975	1.5	
1976	10.0	
1977	10.0	
1978	10.0	
1979	10.0	
1980	15.0	110
1981	20.0	110
1982	20.0	110
1983	20.0	110
1984	20.0	
1985	10.0	
	147.5	440

*Basic Assumptions: 1 professional man year = $\$5 \times 10^4$

1 satellite = $\$27.5\ 10^6$ in orbit (Planning Res. Corporation, 1969)

(b) Ground support systems costs (see Fig. 9.2)

Milestones and Events

(S)* Start 1973 (assumption)

(A) Establishment of Management Authority (part of initial effort already listed)

(B) Ground Systems Preproduction

(1) Engineering Feasibility Studies

*The circles correspond to similar circles on the PERT diagrams.

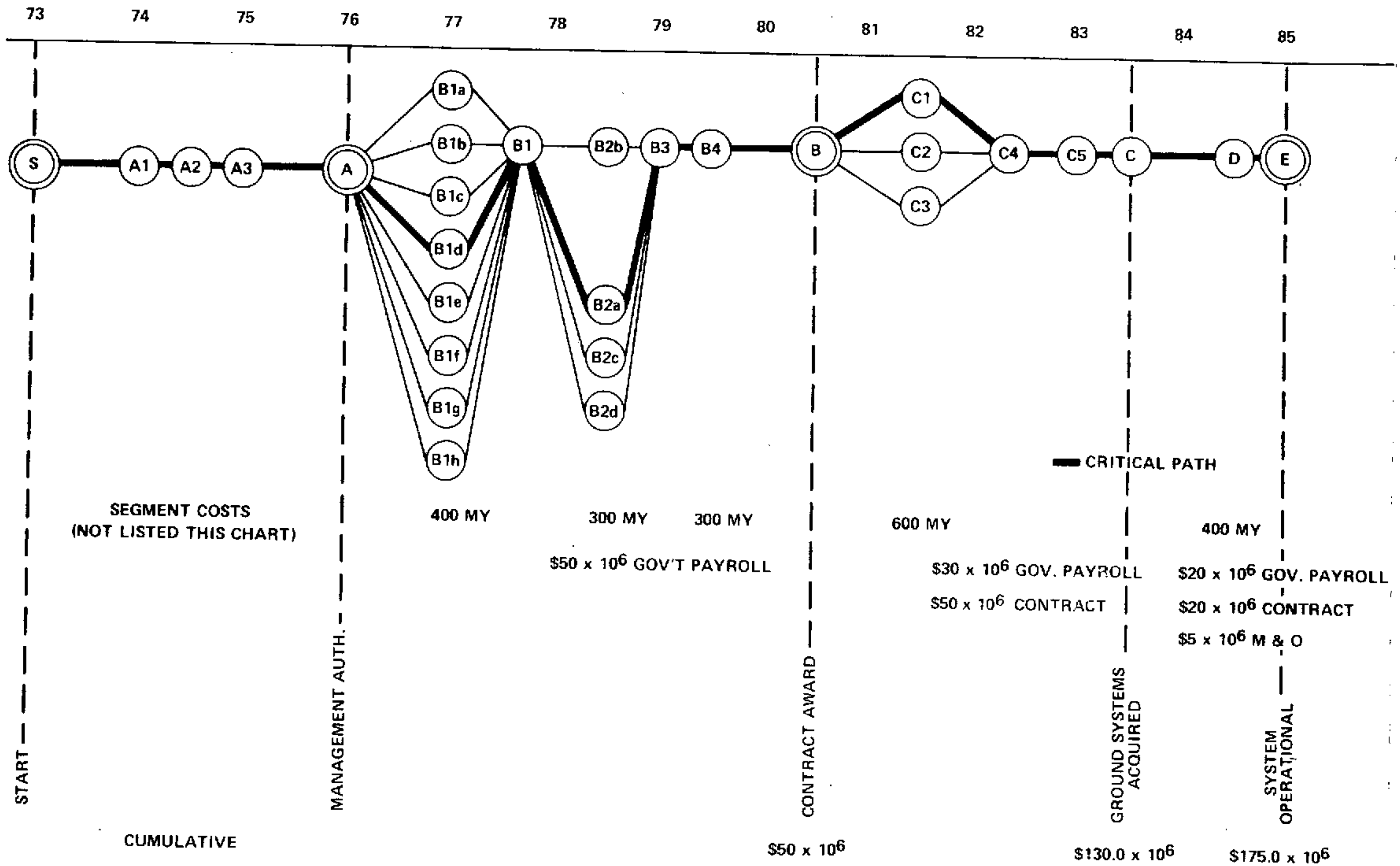

Figure 9.2 Simplified Pert for Ground System

(a) Site Selections
(b) Data Link
(c) Data Processing

} tracking stations

(d) Display (national resources display center)

(e) Communications

(f) Regional Centers

(g) State Centers
(h) Task Force Centers (mobile)

} interface analysis

(2) Systems Design

(a) Hardware Definitive and Configuration

(b) Site Development Planning and A & E

(c) Data Processing Interfacing

(d) Communications Interfacing

(3) Bid Request

(4) Bid Evaluation

(5) Contract Award

Ⓒ Ground Systems Acquisition

(1) Hardware Production

(2) Site Development

(3) Computer Acquisition

(4) Communications Install

(5) Outfitting and Tests

Ⓓ Network Testing

(1) Satellite to Tracking Station

(2) National/Regional

(3) Regional/State

(4) State/Task Force

Ⓔ System Operational

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*The circles correspond to similar circles on the PERT diagrams.

FISCAL ESTIMATES - GROUND SYSTEM

$\$ \times 10^6$ in FY 1973 Dollars

Year	Government Payroll	Government M & O	Vendor Contract (Buy Items)
1973			
1974			
1975			
1976	10.0		
1977	10.0		
1978	10.0		
1979	10.0		
1980	10.0		
1981	10.0		16.6
1982	10.0		16.6
1983	10.0		16.6
1984	10.0	1.0	10.0
1985	10.0	4.0	10.0
	100.0	5.0	70.0

Note: This is Federal Costing and does not include cost below the regional centers.

(c) Funds to support the satellite program

Under the present concept, the satellite system including ground support would be funded by the federal government. There would be a large amount of data made available for public use, and probably the Department of Commerce would control the sale and distribution of it. Reimbursement would probably be for maintenance and operations of the system only. It is suggested that the sale of information from the system would not be for the purpose of capital acquisition of the air/ground basic setup. If we follow this assumption, the peaceful uses of the data could be sold internationally perhaps, or shared on a selected basis to treaty allies by edited presentations from the National Control Center. Once the data leaves the National Center to the Regional Centers, it can be measured and sold on some sort of a data bit basis, time used basis, or other basis.

But these assumptions place the costing of the Satellite Ground Support portion of the overall system out of the boundaries of this study.

Summary Estimated Total for Federal Support in Satellite & Ground (investment to bring the system to operational status in 1985)

Satellite Flight Systems	588×10^6
Ground Systems	175×10^6
	763×10^6
	1973 dollars

(d) Estimating Certainties

The estimates of satellite costs made in this study are "ball park" at best. The technology of satellite launching will be decidedly influenced by the shuttle program proposed for the 1980 era by NASA (Von Braun, 1972). We have used several references in arriving at our own cost figure of $27,500,000 per bird in orbit. This was based on the assumption that each unit would be separately launched at the Vandenberg Air Force Base because of N/S orbit requirements. But we have been guided by the more expensive launch modes in making our estimates (Fishlock, D., 1971), (Planning Research Corp., 1969), (Radiation, Inc., 1973). We have also chosen to make our estimates probably on the high cost side for the ground support portion; however, we were guided by (Grant, H. A., 1972), (Gubin, S. et al, 1971), (Krzyoskowski et al, 1971), (Aerospace, 1972), (DEMR, Canada, 1972).

Should we see continued advances in micro-computer hardware and in reduced launching costs, the overall satellite system estimate of $763,000,000 could be considerably reduced.

2. Command and Control Costs

(Note: the following figures apply only to California State costs. The federal burden is not counted here.)

State Command and Control Center
(California Wildfire Suppression Force CWSF)

Capital costs

Land (Sacramento)	$ 500,000
Buildings (40,000 ft^2 @ $30.00)	1,200,000

Outfit of facilities

Computers	5,000,000
Displays	1,000,000
Power supplies	200,000
Hotel facilities	500,000
Business facilities	500,000
Total capital costs	$8,900,000

Maintenance and Operations (yearly)

Personnel salaries

White collar, red collar (CWSF)	15 @	$18,000	$270,000
Blue Collar Technicians	6 @	12,000	72,000
Security Guard	6 @	12,000	72,000
Expendables (office supplies)			20,000
Repairs			50,000
Power and utilities			15,000
Communication (telephone)			20,000
Training			50,000
Travel and per diem			30,000
Public relations and publications			10,000
Total maintenance and operations			$609,000

Task Force Command and Control Vehicle

It is assumed that there are 100 mobile units and that each one has the following prices for equipment on board:

Capital costs

Vehicle itself	$ 30,000
Communications equipment	15,000
Display equipment	30,000
Minicomputer equipment	25,000
Total capital cost per task force	$100,000
Total for 100 mobile units--capital cost	$10,000,000

Instrumentation for Micrometeorological Sensing

Capital costs

Sensors (400 @ $4,000)	$1,600,000
Total capital cost	$1,600,000

Maintenance and Operations (included under Suppression costs)

It is apparent that here we are getting into a fuzzy boundary for costing purposes. The apportionment of the task force fixed headquarters costs to either command and control or suppression is a comptroller decision rather than a command decision. One rule of thumb is "if it is needed for the passive mission it goes one way, if it is expended on the active fire suppression mission, it goes the other."

3. Suppression Costs (Assuming 100 Task Force Units)

Ground Vehicles and Apparatus (new equipment)

Capital costs

FMC Scouts (2 @ $8,000)	$ 16,000
FMC Tracked personnel carriers (2 @ $35,000)	70,000
FMC Timber cruiser (1)	60,000
Lockheed dragon fire trucks (2 @ $60,000)	120,000
Bulldozers (2 @ $50,000)	100,000
Lockheed dragon tractors (2 @ $30,000)	60,000
High boys (3 @ $10,000)	30,000
Lockheed dragon replenishment trailers (2 @ $45,000)	90,000
Heavy tractors (2 @ $15,000)	30,000
Total capital cost per unit	$576,000
Total capital costs for 100 units	$57,600,000

Maintenance and Operations (yearly) (includes new and old equipment)

Personnel salaries

Red collar (40 @ $15,000; yearly)	$600,000
Red collar (seasonal; 40 @ $3,000)	120,000
Blue collar (6 @ $12,000; yearly)	72,000

White collar (6 @ $10,000; yearly)	$ 60,000
Contract (3 @ $10,000; yearly)	30,000
Expendables, damage and waste	20,000
Repairs	10,000
Training	10,000
Travel and per diem	10,000
Total maintenance and operations costs/unit	$932,000
Total maintenance and operations costs for 100 units	$93,200,000

Air Vehicles and Apparatus (assuming 10 air bases)

Capital costs

(Assumed zero since operations involve a contract negotiation probably on a yearly basis. Hence, all costs are listed under Maintenance and Operations.)

Maintenance and Operations (yearly)

Contract operations/base	$5,000,000
Total M & O costs/base	$5,000,000
Total M & O costs for 10 bases	$50,000,000

4. Logistics (assume 100 ground support bases are needed)

Fixed Logistics Bases

Capital costs

Land (10 acre @ $5,000)	$ 50,000
Buildings (50,000 ft^2 @ $15,000)	750,000
Outfitting of facilities	200,000
Total capital costs/unit	$1,000,000
Total capital costs for 100 units	$100,000,000

Maintenance and Operations (yearly)

Personnel salaries (included under Suppression costs)

Office expendables	$ 5,000
Repairs (tools and fixtures for production)	10,000
Power and utilities	12,000
Communications	12,000
Travel, training, and per diem (under Suppression costs)	
Total M & O costs/base	$39,000
Total M & O costs for 100 bases	$3,900,000

Expendable Inventory at Bases

Capital costs

Costs are all considered on a per year basis and so are lumped under M & O

Maintenance and Operations (yearly)

Level of supply acquisition	$100,000
Storage, handling, and demurrage	10,000
Transportation	100,000
Repairs to inventory	50,000
Casualty losses	50,000
Total M & O costs/base	$310,000
Total M & O costs for 100 bases (ground)	$31,000,000
Air Support M & O costs for 10 air bases	5,000,000
Total M & O costs-expendable-ground and air bases	$36,000,000

B. Summary of System Costs in 1973 Dollars

1. Capital Costs

Satellite	
Air	$588,000,000
Ground	175,000,000
Total capital costs: national level	$763,000,000
Command and control	
State Command and Control Center	$ 8,900,000
Task Force Command and Control Vehicles	10,000,000
Instrumentation (meteorological)	1,600,000
Suppression	
Ground equipment	51,600,000
Aircraft	-0-
Logistics	
Fixed bases (100)	100,000,000
Expendable inventory	-0-
Total capital costs: State level	$232,100,000

2. Maintenance and Operations (yearly)

Satellite	
(assumed federally funded and not included)	
Command and control	
State Command and Control Center	$ 609,000
Suppression	
Ground equipment	93,200,000
Aircraft	50,000,000
Logistics	
Fixed ground bases (100)	3,900,000
Expendable (air and ground bases)	36,000,000
Total M & O costs: State level, yearly	$183,709,000

C. General Comments

The present wildfire control agencies in the State of California have a significant capital investment in the existing firefighting system. The cost plan suggested here assumes that use will be made of the existing bases and equipment in the 1985 era; however, the newer apparatus will require increased base support and the costs of creating the more responsive fire control force, over and above existing, is estimated.

When the capital costs of the Task Force Command and Control Vehicle, Ground Vehicles, and Apparatus are listed in Section 3 of Suppression Operations, it is assumed that these purchases represent the creation of two new and technologically advanced, quick response, divisions of the overall five division Task Force. The other three divisions are assumed to be made up of older apparatus at already established bases. These two new divisions require additional and new home base support, and it is this cost that is estimated in the capital costs in Logistics Section 4.

The manning and operation of the entire Task Force on a yearly budget is on an ongoing five division basis, and includes both old and new bases and equipment.

If we assume that the cost of creating the new Task Force organization can be amortized over a 12 year base, the yearly costs to create and operate the single wildland fire control force would be about $206,000,000. This compares to the $219,000,000 per year now spent by all the firefighting agencies in California on wildland fires (Nelson, 1973).

No claim is made in this study that the single wildland fire control force, organized on task force subcomponents, would save $13,000,000 per year in suppression costs. However, the point can be made that the creation of this type of advanced technology firefighting force probably can be accomplished within the combined budgets of all of the California Wildfire agencies, provided they can agree to a mechanism of sharing the cost burdens through a single force plan. This offers a powerful incentive to pool resources into the common interest of achieving an enhanced fire suppression capability. It also indicates that long range planning toward these objectives should be initiated now by some recognized authority having a large stake in the problem. Since the California Division of Forestry has fire control responsibility for 41,000,000 out of 61,000,000 wildland acres now, it seems the logical agency to undertake this task.

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Chapter X

RECOMMENDATIONS

Chapter X

RECOMMENDATIONS

A. Advanced Technology Recommendations

We believe that it is sound national and state policy to recommend:

(1) A WORLD-WIDE SATELLITE QUASI REAL TIME RESOURCES SCANNING SYSTEM BE IMPLEMENTED BY JOINT FEDERAL AGENCY ACTION

The U.S. Department of Agriculture, the Coast Guard, the Environmental Protection Agency, the National Oceanic and Atmospheric Administration, and many other agencies have common advantages to be gained in the creation of a world-wide satellite observational system that has a semi-real time coverage (say-update every hour). No coordinated effort has been made between the national agencies to jointly sponsor such a system.

The "wildland fire community" should take an active part in promoting and justifying the needs for such peaceful information services even though wildfires may be low on the priority list of those objectives for monitoring. In fact, there is an international need for such data, and a U.S. Federal system could provide these observational services as a gesture of international friendship, perhaps through the office of the United Nations.

It seems appropriate that the NASA should further explore (through concept and cost studies) a worldwide, peaceful, high resolution, resource scanning satellite system for quasi real time use. This effort should be in the nature of a review and proposal for potential Federal Agency interests, and could serve through the State Department as a United States positive peace proposal for all mankind.

(2) DEVELOP AND USE PASSIVE SCANNING SENSORS AND MODERN DISPLAY AND DATA HANDLING HARDWARE IN BOTH THE FEDERAL AND STATE WILDFIRE AGENCIES

The FIRESCOPE Program is the keystone in the bridge of the current technical advance in wildfire suppression command and control. The use of this system will create the design base for the command and control apparatus of the 1985-1995 era. This is a program which currently involves the Federal, State, urban, and county forces in Southern California, and promises to be an outstanding vehicle for test of the TASK FORCE COMMAND concept. FIRESCOPE should be adequately supported and used.

It is suggested that the FIRESCOPE Program management invite a periodic operational audit by operations analysts not associated with the program in order to frame recommendations for further RDT+E improvements in advanced wildfire fighting command and control technology. These reviews should be considered by any committee studying the State of California single wildfire control force proposal.

Large bulk data acquisition capacity and large computer data handling rates are implied in a quasi real time wildfire scanning capability. The acquisition, transfer, and manipulation of these data is a developing technology. FIRESCOPE offers the opportunity for the wildfire technologists to increase their capabilities in the automatic data processing area.

B. Organizational Recommendations

If we look at the assumptions, about half of them are directly associated with the satellite system. This rests on the big IF of the Federal Government getting into the peaceful worldwide resources scanning business. The other premises leave some room for local State of California independent action. Perhaps the most powerful supposition here is that we opt for a single wildland fire control organization. This would simplify the implementation of any overall equipment-development scheme. It is mandatory to guarantee explicit command authority and minimum response time. So that one of the first solid recommendations to be made, in the vein of solutions to California's wildland fire problem for California State Agencies is:

PREPARE A SINGLE WILDLAND FIRE CONTROL ORGANIZATION IMPLEMENTATION PLAN

This plan could be prepared within the State of California Resources Agency, Department of Conservation as an ad-hoc task for the California Division of Forestry. It is suggested that members of the Fire Control subcommittee of the Task Force on California's Wildland Fire Problem be reconvened as an advisory group in this matter. It is further recommended that as part of this study the following areas be given extensive review over the next four years:

(1) Establish several modular Task Forces, at least one in Northern California, one in Central California, and one in Southern California.

(2) Organize and use special logistic service force components in replenishing the requirements of the deployed Task Force.

(3) Test through field usage the advanced off the road vehicles (now available on the market) specifically configured for wildfire suppression, in the Task Force vehicle mix suggested in this study.

(4) Convene an "operations analysis" team during each fire season to make pertinent measurements of fire data on a systematic basis in order to refine "fire theory." It is suggested that this team not be primaily regular members of the active or passive fire suppression organizations, but primarily knowledgeable in operations analysis disciplines. Team observations of the suppression efforts of both the conventional suppression organizations and the developing modular Task Force suppression organizations should be systematically compared; hopefully with suggestions that would improve the operational capabilities of both.

(5) Space the ad hoc task for the CDF over a period of four years, so that at the end of two years a progress summary would be submitted, while at the end of the four year period a definite, single wildfire control force, implementation program would be presented based on hard cost data.

(6) Establish a subcommittee of the suggested advisory committee that would be specially concerned with the recognition and drafting of implementing legislative and legal agreements to create the single wildland fire control force.

(7) Establish a subcommittee of the suggested advisory committee that would be specially concerned with system economics and the assessment of costs and cross charges involved in establishing the single wildland fire control force.

C. Hardware Recommendations

The U.S. Department of Agriculture, Forest Service is presently sponsoring systematic equipment research, development, test, and evaluation programs for fire suppression hardware. Many of the suggestions made for quenching and line building apparatus in this study are not under investigation at the present time. Those new items and clearance techniques suggested in the body of the report are believed worthy of further investigations as RDT+E tasks at the Missoula and San Dimas laboratories. Our specific areas of hardware interest have been in Personnel Safety, Engineering for personnel back pack tools, and Engineering for multifunctional purposes.

Part of the uncertainty in the assignment of forces in suppression operations is the capability of people equipped with various apparatus to quench or build lines within bounded rates. This is the inverse of the "Fire spread model." Definitive tests should be attempted to rate various suppression techniques against a variety of potential spread rates. Such inferential studies would be of importance in generating dispatching doctrine in situations of high fire danger rating that would be memory stored in a central command control center.

Our recommendation for the Forest Service in this regard is then:

BOOST EQUIPMENT DEVELOPMENT AND TEST PROGRAMS FOR WILDLAND FIRE SUPPRESSION IN ORDER TO OBTAIN QUANTIFIED SUPPRESSION CAPABILITY ASSESSMENTS

D. Software Recommendations

The wildland inventory coupled together with a highly reliable fire spread model will allow the wildland fire control management in the 1980's to make decisions that are quite frankly almost impossible to do now. The reason for this is that currently no such data base exists and very little objective data is available about fire spread behavior. The current lack of fire statistics ties the hands of the wildland fire management by not giving them the necessary tools for use in their decision making. Any satellite based inventory system even the present ERTS "A" induces fire management to pursue prevention techniques that otherwise are denied to them. For instance, "let burns" and "prescribe burns" can be carried out with a high probability of success knowing a priori that a fire will not "get away." Inspections of wildlands for enforcement purposes, fire insurance statistics, zoning regulation, and use and entry procedures may become standard management practices in a future period.

The predicted future change in management procedures implies that new problem areas will develop. Today's wildland management must be made aware of these potential beneficial changes and direct their resources to pursue them, therefore it is suggested that the following recommendation be given special attention by the Forest Service:

ANALYZE CURRENT 1973 ERTS AND GEOSYNCHRONOUS GOES SATELLITE INFORMATION IN ORDER TO:

(1) Develop detection algorithms specifically geared to wildland inventory.

(2) Develop new fire management procedures to take advantage of the wildland inventory system and a highly reliable fire spread model.

(3) Develop efficient methods of information storage and retrieval such that fire management decisions can be implemented.

(4) Develop hardware and software to integrate potential satellite systems into the present wildland management scheme.

(5) Initiate research on vehicle location at fires using satellite based sensors.

(6) Develop a system whereby fire behavior statistics can be documented by using the satellite system.