Operations Research Models and

Aircraft Use for Fire Control in North America

Introduction

During the last two decades there has been a steady increase in the use of aircraft for fire control in North America. The United States Forest Service, for example, used approximately 17000 hours of aircraft flight time for fire control purposes in 1956 and since then has been increasing its usage an average of 4000 hours per year (see figure 1). In 1970 the USFS used approximately 85000 hours of aircraft flight time in fire control related activity (1)(2). An examination of the deflated USFS forest fire protection budgets during this same period shows that a remarkably constant level of annual expenditure was maintained (27). Thus even while the total level of real expenditures in fire protection was being held constant aircraft useage was expanding.

Unfortunately data on Canadian use of aircraft are limited, but based on what information is available it would appear that
experience
their expenditure is comparable to that of the USFS. In 1970 the total number of hours flown by the Canadians for fire control was 55000, and the growth in the number of aircraft used as airtankers had been 27 percent over the previous three years, from 1967 to 1970 (3).

The cost of aircraft operations is significant. The direct operating costs of an aircraft will range from 200 to 600 dollars per hour depending on the aircraft type and its mission (3). Even ignoring the substantial indirect costs associated with the use of aircraft, an average hourly operating cost of 400 dollars would imply an expenditure of 34 millions of dollars by the USFS in 1970 on aircraft operating costs alone.[1]

Further indication of a common, parallel Canadian experience in this regard is indicated by the ninth resolution of the 1970 National Forest Fire Seminar on Aircraft Management (14):

> Whereas: aerial attack is a high cost fire control technique,
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> and whereas: the airtanker is being increasingly used,
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> and whereas: an increasing proportion of fire control budgets are being expended in aerial attack,
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> and whereas: research projects such as studies of drop pattern requirements and release systems are desirable,
>
> be it resolved that: the Associate Committee promote and support by every means at its disposal

1/ "Imply" because tracing down and identifying the true magnitude of these costs using the published budget figures is impossible as all bureaucrats, accountants and economists recognize, cheerfully or otherwise.

those research studies that will contribute to a more efficient application of the air-tanker.

What then is the role of the aircraft in fire control that entails such large expenditures? What factors have encouraged the disproportionate increase in the use of aircraft over alternatives? How is such an expensive resource managed? And, finally, how have operations researchers responded to the problems facing aircraft managers.

Aircraft Roles in Fire Control

Three aircraft missions account for the major portion of aircraft expenditures: reconnaissance, transportation and fire retardant delivery.

Under the general heading of reconnaissance are found two subcategories: detection, and, monitoring and command. There has been a strong movement towards airborne fire detection systems either supplementing or actually supplanting existing fixed ground surveillance (21)(22). Likewise, the monitoring of going fires has been found to be easily conducted from the air, and command decisions are accordingly facilitated from this vantage point.

Transportation of fire personnel and equipment by air is increasing both in the movement of local resources and, in the case of campaign fires, the movement of regional and national resources.

Air tanker retardant delivery systems, the most spectacular use of aircraft, have also steadily expanded over the last two decades.

Two minor roles of aircraft are their use in remote ignition during large scale backfiring operations (5), and cloud seeding under suitable weather conditions in advance of large fires (6).

Factors Encouraging the Use of Aircraft

The steady growth in the use of aircraft has been brought about by a number of economic factors, consistent in the direction of their impact and of ever increasing importance.

The rising cost of labor has strongly motivated a shift towards capital intensive means of production. Specially trained crews and their equipment are now moved long distances, by aircraft, to the site of campaign fires. The necessity of maintaining high manpower leads in local forces--at low usage levels --is thereby reduced. Fire lookouts, once manned continuously through high--and low--fire danger days, are now replaced by air patrols closely keyed to the fire danger level. With the aid of airtankers smaller ground force crews are now needed to control fires on initial attack.

The increasing value of the wildland resource has brought political pressure on fire control agencies to reduce fire damage below current levels. Only by reducing the damage caused by those 1-2 percent of the large fires which cause 80-90 percent of the damage can significant progress be made. Only the higher level of fire control gained by proper initial attack utilization of the aircraft's unique speed, mobility and high impact attack can currently meet this demand for further significant reduction in damages. Especially is this true in the case of isolated, extensive resources such as those found in Canada, Alaska and some parts of the contiguous United States.

The aircraft has become an increasingly effective element within the fire control system. Operational experience has taught fire control managers how they can most effectivley use the aircraft at their disposal. Concurrently, aircraft design has progressed in such areas as retardant tank design and infrared scanning systems. The full technological potential of the aircraft is thus closer to being realized even as that technological frontier continues to expand.

The capital cost associated with most aircraft now in use has been held down by the few alternative uses of obsolete war surplus aircraft. Even into the foreseeable future sufficient low cost aircraft should be available (4).

Likewise an increasingly large number of qualified air and ground personnel have become available and their numbers continue to grow.

In summary, the disproportionate increase in aircraft use has been encouraged by: 1. capital substitution, 2. intensification of the fire suppression effort in response to increasing wildland resource values, 3. increased technological efficiency in aircraft design and use, 4. limited alternative uses of the available aircraft, and 5. a rapidly expanding pool of trained ground and air personnel.

Aircraft Management

Although some fire control agencies have purchased aircraft outright, most of the aircraft used in fire control in North America are contracted from private operat~~ions~~ors on a seasonal and/or emergency basis. Two significant advantages of contractual arrangements are: 1. the opportunity of changing aircraft from one contract period to the next in response to changing fire control needs and advances in aircraft design; and, 2. the realization of lower costs if it is a single purpose aircraft or if an acceptable level of aircraft utilization cannot be maintained over the year by the organization.

There has been wide variation between agencies in specifications and terms of air service contracts, although within certain agencies such as the USFS nationwide standard contracts have been used for some time (4)(7). Some inter-agency convergence towards a standard contract might be expected in the future.

Adequate management rests on the existence of written instructions for personnel qualifications, suitable aircraft, effective tactics, and operational requirements. The content of these instructions are specific to the aircraft mission. Since the brevity of this paper precludes elaboration the interested reader is referred to the following references: the Forest Service Handbook and Manual for the United States Forest Service, the Manual of Instructions and the Fire Control Manual of the CDF, and A Guide to Effective Use of Air Tankers for Forest Officers (23)(24)(25)(26).[2]

A general consensus seems to have developed that it is in the area of aircraft management where the most work remains to be done. Attempts to increase productivity and to reduce cost should properly focus on these aforementioned points of adequate aircraft management (4).

Operations Research in Aircraft Management

The technique of operations research (OR) have been applied to the fire control aircraft roles of detection, transport, and retardant delivery.

Peter Kourtz of the Canadian Forest Fire Research Institute has done extensive OR modeling of the fire detection mission. His earliest work in this field was a cost-effectiveness

2/ NOTE: Each Province of Canada has primary protection responsibility for its forest and considerable variation in operational procedures may be found.

simulation model designed to calculate the best combination of fixed lookouts and aircraft for a given budget level (8). In later work he has focused-in on the scheduling and routing of fire detection aircraft through simulation and DP (9). This work in conjunction with the continuing work of David Martell, who is refining the decision information available both prior to and subsequent to detection aircraft flights should lead to major changes in fire detection system operations (10).

The OR analysis of airtanker systems has been directed towards answering three primary questions: 1. given a limited budget which aircraft should be contracted for the coming fire season and where should they be stationed; 2. given a limited budget and a set of airtankers contracted for the season how should they be transferred among airbases during the season in response to shifting fire suppression force demand, and, 3. what is the behavior of an airtnaker transfer system under different assumptions about its organizational structure.

In responding to the first question James Maloney has given the most detailed analysis to date (11)(12). Using a linear programming model the full California Division of Forestry (CDF) airtanker system (consisting of 12 airbases and 21 airtankers in 1969) was examined.

Perhaps the most interesting result of this analysis was the apparent efficiency of existing CDF airtanker allocations.

Savings of from 4.4 to 8.3 percent of CDF operational costs might possibly be realized using model derived results; but savings of this magnitude are ellusive all the more so when simplifying model assumptions and unrecognized constraints are allowed for in application.

Simulation models have also been proposed. Neuberger has constructed and used a simulation model which has as its primary objective the evaluation of different aircraft types (13). Much attention was directed at the development of a fire suppression model, still perhaps the weakest point in the model. Stade had proposed a somewhat similar approach in an earlier memorandum (14).

No simulation model has been implemented to the extent of fully answering this first question and the previously mentioned LP model offers the only approach generally applicable.

An airtanker model which derives optimal transfer/use rules for a given system of airtankers and airbases has been developed (15)(16). Through a linear programming formulation the expected total initial attack output over the season is maximized subject to an operating budget constraint. Transfer of the aircraft is based on expected initial attack demand at the different airbases for the current day.

An application of the model to CDF District I was carried out. In 1967 this District had three airbases and fire aircraft. While the feasibility of the technique was fully demonstrated in this particular case it must be noted that the size of the system, in the number of airbases, must be relatively small in order to be solved by this method.

A logical extension of this work is an attempt to give a simultaneous answer to both the question of airtanker transfer/use and the problem of which aircraft/home bases to select for the season. The Canadians are currently exploring the use of simulation models (29)(30), while here in the United States the USFS is funding a project in which linear programming is the solution technique being applied (31).

Al Simard has completed a preliminary analysis of a proposed Canada-wide airtanker fleet through continuous system simulation (17). It is his opinion that potential returns from an analysis of alternative institutional designs can be expected to be substantially higher than the returns from the solution of any other problem related to airtanker operation. This model is in an early stage of development but the continued need for research on this problem is widely recognized (4).

Operations research analysis of the use of transport aircraft is very limited. In an early paper Parks examines, among other factors, the relationships between initial attack travel time, crew size and final fire size (18). His modelling results strongly indicated the value of reducing initial attack travel time through the use of helicopters to transport suppression crews. This study used data from the Plumas National Forest in California, and partially as a consequence of this study helicopters are now commonly used in that forest on initial attack.

In a paper presented at the Joint National ORSA-TIMS Meeting of November, 1961 held in San Francisco, California Professor Paul Casamajor of the University of California concluded his presentation with the observation that operations researchers can contribute most to the solution of the wildland fire problem by finding ways to detect and suppress fires before they get large (19). One of the most promising techniques in this regard is the effective use of aircraft in detection and suppression. Yet, almost ten years later, in October of 1970 at the National Forest Fire Seminar on Aircraft Management in Chalk River, Ontario it was stressed that airtanker initial attack effectiveness is highly dependent on an adequate detection system, and that the existing detection system was deficient in many areas (4). The net result is that neither subsystem is performing as well as expected.

The model building pace has been slow, but even slower has been the movement towards application of modelling results.

Asside from the ubiquitous practical problems of application there are theoretical problems. The wildland fire problem has been attacked through the modelling subsystems; e.g., fire detection, airtanker initial attack, etc. A major difficulty has been the complexity of the subsystems and the linkages between subsystems. It is extremely difficult to specify a "stand alone" measure of subsystem output which is meaningful to the fire manager/decision maker. For example, to be able to give an effectiveness measure of the detection subsystem both the fire and the initial attack subsystems must also be specified (8)(22). Unfortunately this specification, since it is either of secondary interest to the model builder or of a complexity exceeding the scope of the project, is frequently of a vitiatingly trivial nature.

The one most critical subsystem has been fire--more specifically the behavior of those 1-2 percent of the fires which exceed 300 acres. Significant progress has been made in this area of research in the last few years (20)(28). This advance along with efforts to merge existing, well-specified subsystems should eventually yield measures of output of acceptable accuracy which can be easily evaluated by decision makers. Until the decision maker receives what he interprets to be credible, easily understood measures of output progress in application of operations research models will be slow.

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Data for Figure 1

Year	Hours
1956	17273
1957	20931
1958	27029
1959	32746
1960	47861
1961	61739
1962	29269
1963	39198
1964	35114
1965	31095
1966	56353
1967-1969	missing
1970	84750
1971	73897
1972	85152
1973	92361