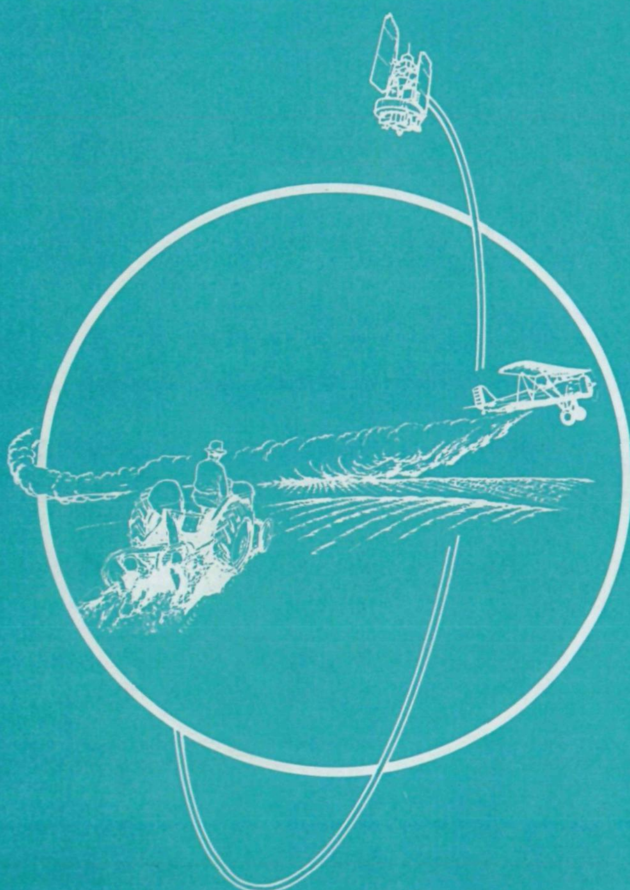
The Role of Aerospace Technology in Agriculture



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16. Abstract

The report summarizes a study, the goal of which was to improve productivity of agriculture through aerospace technology. An overview of agriculture and of the problems of feeding a growing world population are presented. The present state of agriculture, of plant and animal culture, and agri-business are reviewed. Also analyzed are the various systems for remote sensing, particularly applications to agriculture. The report recommends additional research and technology in the areas of aerial application of chemicals, of remote sensing systems, of weather and climate investigations, and of air vehicle design. Also, considered in detail are the social cultural, legal, economic, and political results of intensification of technical applications to agriculture.

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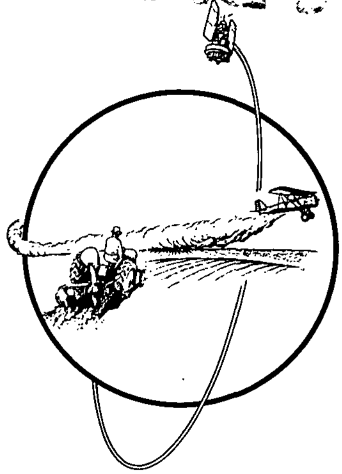
THE ROLE OF AEROSPACE TECHNOLOGY IN AGRICULTURE



1977 SUMMER

FACULTY FELLOWSHIP PROGRAM IN ENGINEERING SYSTEMS DESIGN

NASA-LANGLEY RESEARCH CENTER

AMERICAN SOCIETY FOR ENGINEERING EDUCATION

OLD DOMINION UNIVERSITY RESEARCH FOUNDATION

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FOREWORD

This document summarizes results of the 1977 NASA-ASEE Summer Faculty Program in Engineering Systems Design conducted at the NASA-Langley Research Center in Hampton, Virginia during the period June 6 through August 19. The program was sponsored jointly by the National Aeronautics and Space Administration and the American Society for Engineering Education through a contract by NASA (NGT-028) to Old Dominion University Research Foundation of Old Dominion University.

Included among objectives of this program were (1) provision of a framework for communication and collaboration between academic personnel, research engineers, and scientists in governmental agencies and private industry, (2) useful study of a broadly based societal problem requiring coordinated efforts of a multidisciplinary team, and (3) generation of participant experience and interest in development of systems design activities and multidisciplinary programs at the participants' home institutions.

These three objectives were met through a study of one of the most important problems confronting the world today, that is, production of a sufficient supply of food for the growing human population of the Earth.

This problem is a very real and immediate one; the problem, as posed by Dr. Bruce Holmes is, "Based on current and projected technology, what impact might NASA have on the entire agriculture system?" A pre-requisite to answering this question is knowledge of the difficulties encountered in various agricultural processes. The extent to which these difficulties can be alleviated through use of aerospace technology may then be assessed.

It is highly important to view the agricultural system as broadly as possible. Technology assessment is meaningful only to the extent that technological innovations are analyzed in terms of their effects upon society. The problem of applying aerospace technology to agriculture is marked, not only by the many technical disciplines involved, such as aeronautics, chemistry, geography, biology, engineering, agronomy and physics, but also by social, political, religious and economic reactions to perturbations in agriculture production which are global in extent and vitally important.

This report constitutes a broad look at the agricultural system of the United States in the context of world needs. Difficulties encountered in operating this system are discussed, and desirable avenues for applying aerospace technology are suggested. In fact, one may consider this report to be a preliminary design for research and technology needs to improve agriculture production.

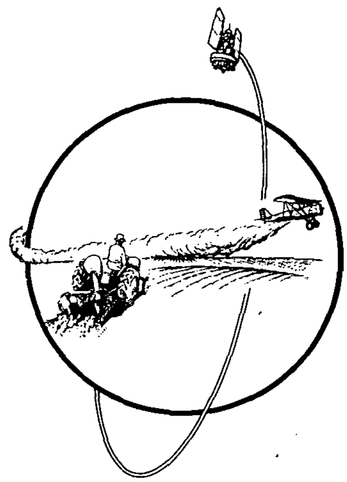
To assure awareness and testing of many points of view, and to achieve some convergence of best ideas, a group of 21 investigators was assembled. The design team represented 16 different colleges and universities, and 17 academic disciplines - agricultural engineering, aeronautical engineering, chemistry, civil engineering, economics, electrical engineering, engineering management, geography, law, mathematics, mechanical engineering, oceanography, physiology, physics, political science, sociology, and technical sciences.

Although the presence of a multidisciplinary team has been essential to the success of this study, the program itself has been enhanced by guest lecturers and consultants (see Appendices C and D). Additionally, particular appreciation is expressed for administrative support provided by Co-Directors of the NASA-ASEE Summer Institutes, Dr. G. L. Goglia of Old Dominion University and Dr. John E. Duberg of NASA-Langley. The assistance of Mr. John Witherspoon of the NASA-Langley Personnel Training and Educational Services Branch, Personnel Division, was indispensable to the functioning of the program.

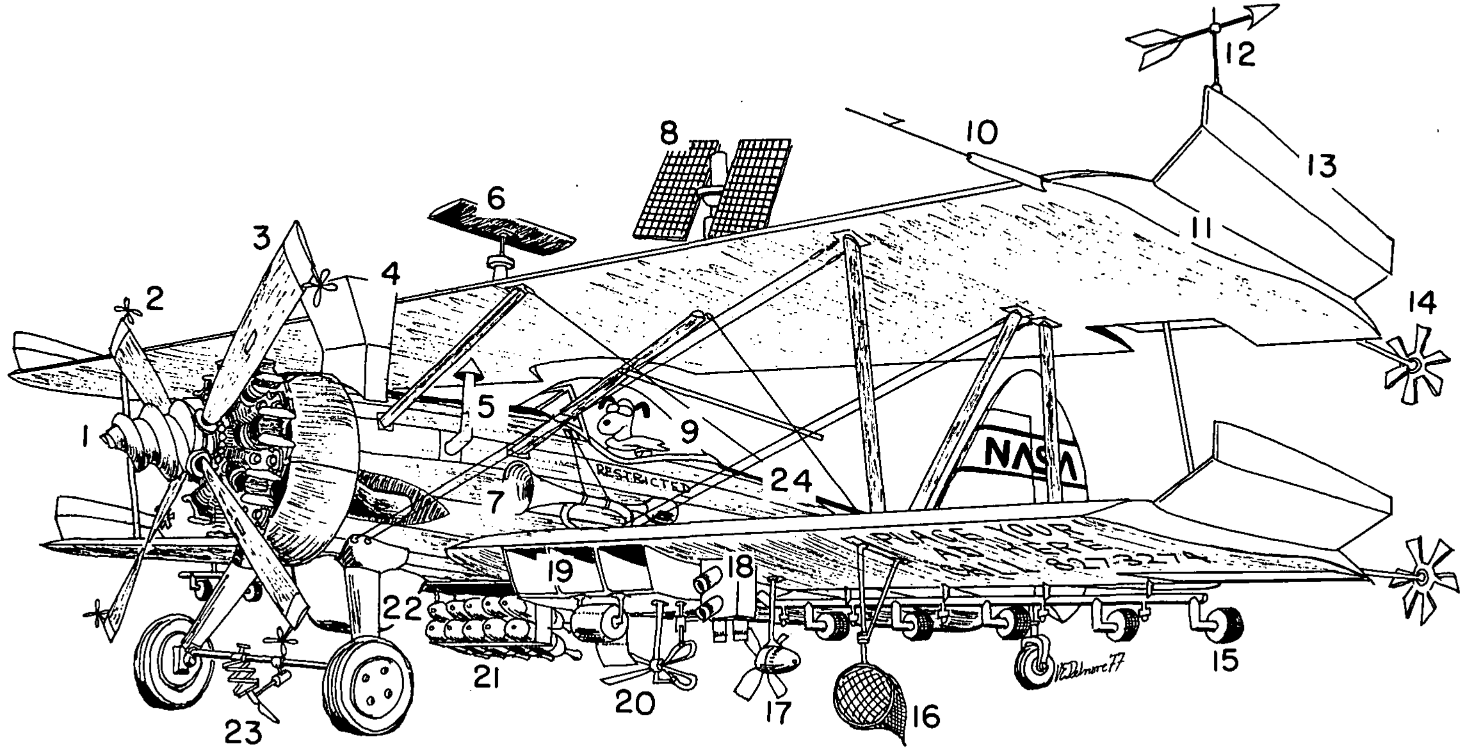
Dr. Bruce Holmes of NASA-Langley served as technical advisor to the Design Team. He was a knowledgeable and helpful mentor, and the participants express their appreciation of his help.

Griffith J. McRee, Project Director
Melvin H. Snyder, Assistant Project Director

19 August 1977



SUMMARY OF RECOMMENDATIONS



THE AG-DOG

INCORPORATING SEVERAL NEW NASA-INSPIRED FEATURES DEEMED TO BE OF INESTIMABLE VALUE IN THE IMPROVEMENT OF AG-AIR OPERATIONS.

1. A true air-screw
2. Splines to break up vortices generated by blade tips
3. Another one of those fancy NASA propellers
4. Quick-fill hopper chute.
5. Rain-proof hopper-level indicator
6. Navigation radar.
7. Audible collision-avoidance warning device.
8. Sun-direction-seeking solar cells to power stereo, CB radio, air conditioner,etc.
9. Bubble canopy for protection from chemicals.
10. Relative wind-speed detector.
11. Another one of those fancy super-critical airfoil shapes from NASA
12. Relative wind direction indicators (to insure cross-wind swaths).
13. Spoilers for vortex-breakup
14. Splines for vortex-breakup
15. Combination nozzle/spin-atomizer rack (we still don't know which method is better).
16. Net for inflight sampling of insect populations.
17. Transverse fan to compensate the asymmetry in distribution due to the main propeller.
18. Multi-spectral remote sensing camera.
19. Intakes for ram-air (but really for the air conditioner).
20. Dispensing system for end-of-swath markers
21. JATO or RATO bottles (one per swath) for fast altitude gain at end of swath.
22. Sound transducer (echo sounder) for altitude determination
23. Retractable knife blade for cutting power lines.
24. As always, your old basic Stearman.

SUMMARY OF RECOMMENDATIONS

This section summarizes the processes and findings of the 1977 NASA-ASEE Langley design team. Because the topic, "Improving Agriculture Through Aerospace Technology", was broad, our recommendations were numerous. It is necessary therefore to highlight those research areas where technology could have the greatest potential benefits to agriculture.

Process: After much debate, the team decided to focus upon the world food system using a systems design framework. In order to make intelligent recommendations regarding the applications of aerospace technology to agriculture, the team employed several procedures: the relevant literature was rigorously reviewed; ideas and concepts were debated among the team members; new information was synthesized with the experience and expertise of the team membership. It was this synthesis which generated criteria upon which the applications of aerospace technology to agriculture were evaluated. (A complete discussion of the organization and process can be found in Appendix E)

Social-Cultural Impacts: The team believes that aerospace technology can significantly improve the techniques of agricultural production. The team has expressed concern, however, that all new technologies be evaluated on the basis of their potential social and cultural impacts upon society. In overview we recommend that a social-cultural impact statement be prepared before the introduction of any new technology. This statement should consider the problems raised in Chapter 7 (e.g., the displacement of marginal agricultural laborers as a result of increased mechanization.) and also seek to discover new interfaces between society and technology. Unless social impacts are considered as routinely as economic or environmental criteria, social disfunctions may result which outweigh the gains made from new technology.

Aircraft Application System: Chapter 5 contains a number of research recommendations in the area of aircraft application systems. Those recommendations containing the most promise are summarized here.

Aerial dispersal systems should be integrated into the design of the aircraft. The current practice of hanging a dispersal system on an aircraft produces unnecessary drag which acts as a drain on the power system of the aircraft. The drag reduction that would result from an integrated system would increase ferry speed and thereby cut costs.

Improvements in the guidance and control of aerial dispersal vehicles is also a potentially fruitful area for research. An optimal design would, of necessity, relate the density of material reaching the target areas to aircraft motion and dispersal rate. The technology for accomplishing this is available; however, implementation problems persist and must first be resolved. A less than optimal, but realizable solution, relating dispersal rate to ground speed is suggested in Chapter 5.

Remote Sensing: Applications in this area can contribute greatly to the effective production of food and fiber. While the capabilities of remote sensing are well established, advances in the following areas should prove particularly beneficial.

1. Thermal infrared remote sensing of agriculture utilizing Landsat-C and the satellites which will evolve from it.

2. A thorough evaluation of the procedures currently used to disseminate data produced by satellite remote sensing. Particular attention should be paid to areas where turnaround time could be reduced at a low cost. The feasibility of regional browsing centers for the purpose of greater user accessibility should be examined.

3. An in-depth survey of current and potential users of remote sensing data. The survey should reveal the types of users who currently utilize remote sensing for research as opposed to routine activities, and the degree of reliability and timeliness required by specific categories of researchers.

4. Exploration by economists of the possibility of developing a decision matrix that would show which remote sensing data are most beneficial to the user.

5. Continued R & T in experiments similar to LACIE which would coordinate Landsat data with SRS (Statistical Reporting Service) surveys to reduce errors in crop acreage estimates.

Weather Prediction and Modification: Research in these areas may not produce immediate benefits but does have the potential for long run payoffs and certainly justifies this undertaking. The team specifically recommends that the techniques used to observe weather variables should be developed with enough statistical accuracy to distinguish actual climate trends from normal weather fluctuations. Numerical models capable of handling the observed weather and climate data should be developed for the purpose of improving forecasting.

The conditions under which precipitation can be increased, decreased, and redistributed should be identified. Finally, technology directed toward the mitigation of the effects of tornadoes, hurricanes, hailstorms, fog, and lightning should be developed.

Supporting Research: Much of the research most needed to improve agricultural production lies outside the purview of NASA. For example, research is needed to better understand the life cycles of plants and pests and the interaction of both with chemicals and the micro-environment. Until basic research provides an accurate body of knowledge regarding the natural processes associated with agriculture, we cannot hope to know how best to superimpose technology.

Ancillary topics: Chapter 8 contains recommendations in subject areas which are ancillary to the mainstream of the study. They are important nonetheless. The reader's attention is especially directed to the legal questions relevant to agriculture.

Conclusion: Many of the research recommendations contained herein are not novel. That others have been drawn to the same conclusions only adds weight to the substance of our findings. The evidence clearly indicates that the current bounty of world wheat production is merely a hiatus in the ever-growing problem of effectively feeding a growing population. These research recommendations are therefore offered as vital components in the solution to this long term problem of the world food system.

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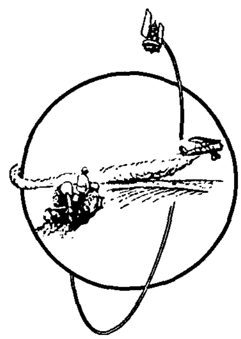
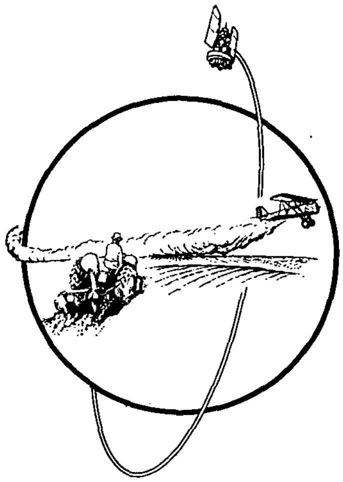


PART I

Description of the Agricultural Production System



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State of the System

CHAPTER 1

ANALYSIS OF THE AGRICULTURAL PRODUCTION SYSTEM

Before undertaking an analysis of how aerospace technology can be applied to agricultural production, a comprehensive understanding of the production system itself is essential. This study was begun with an effort to obtain such an understanding. Since the system is such an extensive one, this study, should it attempt to be exhaustive, would result in a report filling many volumes. Such an exhaustive study was not an objective; rather, specific constraints were formulated in order to direct the efforts of participants. These constraints stemmed principally from the fact that the study group was concerned with those aspects of agricultural production having potential to be significantly affected by aerospace technology. The decision was made that "aerospace technology" meant systems and devices which operate above the ground. Thus new developments in tractors would not be considered while new developments in, say, rotary wing aircraft would be. This constraint, then permitted focusing the in-depth analyses on certain highlighted system functions.

In spite of the desire to concentrate our attention on selected system functions, there was full awareness of global system interactions which spread widely the impacts of application of specific technology.

Initial efforts to obtain this comprehensive understanding were made with full cognizance that agriculture is a complex system of interrelated and interacting parts that cannot be discussed in isolation nor limited to a single locality. The system is world-wide. The system objectives are interdependent; for instance, it is in the interest of the poor of the world to spend the smallest fraction of their total income on food, just as it is in the interest of the American farmer to get the highest return for his produce. Domestic prices are affected by world market prices; in fact, all advanced agriculture is becoming international in scope.

In order to not lose sight of this interrelationship of the various parts, a conceptual framework was constructed within which those elements of the system that correspond to the expertise of individuals making up the study group are described in greater detail. This group expertise is another constraint on the analysis.

The experience of this group is not unlike that of a number of MIT economists who were looking into the problem of feeding the hungry of the world. While each participant brought to the problem his expertise in a given discipline, his solution was only partial. "Agriculture", it was decided, is a system problem. It will perform effectively not if one or two or even several requirements are met but only if a whold range of interacting conditions is satisfied." (ref.1).

The system description devised for this study consists of four major parts at the same hierarchial level:

1. Plant and Animal Culture

2. Environment and Resources

3. Support Services (i.e., Government and Industry)

4. Socio-Cultural Interaction

This is to say, in order to discuss agriculture, one must include culture of plants and animals that are used in production of food and fiber. In addition, the environment in which agricultural activity takes place and resources to be found in this environment to carry on the activity must be discussed. The laws, the governmental regulations and supports, and all the technical equipment developed by industry which guide, hinder, restrict or make possible the various tasks performed in agricultural production compose a vital segment. Also, so long as agricultural activities are carried on by human beings there are socio-cultural interactions involving religion and tradition, law abiding or flaunting, esthetic and utilitarian outlooks upon life, and a host of other factors. This system puts these aspects of agricultural production on the same hierarchial level because they all operate simultaneously on the same plane. They cannot be ignored or reduced to lower level urgency without one's view of the system becoming myopic.

Each of the four major headings may be divided into subsystems which more completely categorize the constituents of those components.

Subsystems of the first major component, Plant and Animal Culture, are (Figure 1-1):

A. Preparing

B. Planting

C. Growing

D. Harvesting

This component is the arena in which the farmer intervenes in the life cycle of plants and animals by preparing the soil and farm structures, planting and stocking, fertilizing and feeding, irrigating and watering, controlling pests, protecting against fires and storms, and harvesting. These acts which increase yields distinguish modern American agriculture from that of less developed countries.

In Chapter 5 of this report we shall examine the role of aerospace technology in the culture of plants and animals. Specific aerospace technologies examined in detail include aircraft and dispersal systems designed for the aerial application of seeds, insecticides, herbicides, etc. In order to discuss the development of this aerial applications technology, it is necessary to examine in detail the biological and chemical needs of plants, methods for disease and pest control, chemicals and chemical formulations of fertilizers, pesticides, etc. and the micrometeorological environment of the plants which affect transport of chemicals to the target. From these studies a number of areas for further research are defined.

The second major component of this study is: Environment and Resources. Subsumed under this component of the agricultural system is an accurate land use inventory including such physical prerequisites of agriculture as water, level land, wetlands and forests. In developing countries, governmental decisions about converting forest lands to cropland and deserts to ranges have put great demands upon the capabilities of remote sensing, especially from satellites. Resource management is closely linked to inventory and decision making.

The spread of disease may be effectively detected and monitored by satel lite remote sensing of the afflicted plant stresses. It appears that satellite remote sensing is in the process of developing capabilities of monitoring crop health, a capability that high flying aircraft have already well demonstrated (ref. 2).

Indispensible to the smooth functioning of the agricultural system is a world wide crop inventory and harvest forecast. Remote sensing satellites of the future (Landsat D and beyond) are being designed to have the higher resolutions and discrete spectral bands necessary to determine crop signatures. Consultants to NASA are estimating the dollar value of crop harvest forecasts by remote sensing to justify continued research along these lines. World crop inventory systems help to predict harvest variations with the goal of decreasing price instabilities that are natural to agriculture. Planning for food storage and distribution would be greatly aided by timely information obtained by remote sensing systems.

Also contained in the second major component is weather and climate observation and dissemination of the resulting data. Long range weather forecasting is based on observation of global meteorological systems for which satellites are ideally suited. On the other hand, weather modification by aircraft is still in the experimental stage. World crop production fluctuations due to weather conditions are often of sufficient magnitude to produce surplus or deficit of available commodities. Accurate information, advance warning, and technology to modify are indispensible in the effort to "improve" agriculture.

The third major component deals with Support Services necessary to maintain a functioning system. Support Services are furnished both by government and industry. Governmental support is necessary in farm price stabilization, in water allocation legislation, and in the dissemination of information via extension services. To improve agricultural production the farmer needs transportation facilities, market development complete with storage, credit to tide the farmer over the long period between planting and selling his crop, and economic assistance in determining cost and price. Much of this aspect of agriculture is government controlled.

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The industrial and commercial aspects of support services are often referred to as "ag-business" which includes design, manufacturing, and marketing of machinery--both ground equipment and ag-aircraft. Chemicals, fuel, chemical-handling equipment, and farm buildings, are a few of the support service included.

The fourth component is Socio-Cultural Interaction. On a world scale, agriculture requires the cooperation of millions of farmers who function on different levels of tradition, knowledge, motivation, governmental organization, standards of living, technology, and environmental priority. It is very difficult to generalize when dealing with such a variety of social systems. The best that can be said is that introduction of new technology, anywhere in the world, will have to take into account the value system of the given social milieu.

As agriculture moves into the modern age, levels of knowledge and education of farmers must be raised. Ease of production is likely to be increased. These changes will bring about social and organizational adjustments that will effect family and political structure and the economy. The educational system will have to train the local social infra-structure that supports and produces further changes.

Governments and planners will be hard put to establish an order of priority when contemplating the need to adapt subsystems, such as education or the local political organizations, to accomodate the modernization of agriculture. Systems design is meant to facilitate such decisions.

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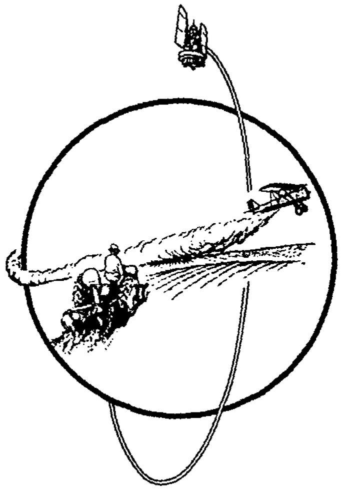


History of Involvement of Aviation and of Space Systems with Agricultural Production

Chapter 2

AEROSPACE INVOLVEMENT WITH AGRICULTURE

The employment of aerospace technology in agriculture has two components. One component is the sensing of the earth's surface and atmosphere and their effects on agriculture. The other component is use of aircraft to interact with the land - to seed, to spread fertilizers, herbicides, and insecticides, to stock fish, and in some cases, to transport agricultural products.

Parallel development of these two components has occurred during this century. Outlines of the development of agricultural aviation and of remote sensing follow.

2.1 HISTORY OF AGRICULTURAL AVIATION

Early Development (1910-1940)

In any area of technological development there are many "firsts" reported. Many times it is very difficult to determine a precise date of a "first use" of any kind of technology. Agricultural activities through use of aircraft is no different. Documented first usage of aircraft for agricultural purposes includes a patent granted in 1911 to Alfred Zimmerman, a German forester, which covers proposed application of chemicals to control forest insects (ref. 1). Little is known of the actual benefit from this early attempt to employ aircraft for agriculture.

Other early reported use of aircraft or lighter-than-air vehicles for agriculture includes the practice of a New Zealand farmer, John Clayton, who used a tethered balloon to seed a swampy area which could not be seeded by regular ground equipment (ref. 2). A sack of seed with a controlled discharge tube was hung from the balloon and pulled back and forth by men at each end of the field, in order to sow the seed. Use of aircraft for applying chemicals to control agricultural and forest pests was envisioned by many people in many countries prior to World War I. However, these early ideas had to deal with the realities of aircraft that were not powerful enough or structurally sound enough to perform that type operation. Suitable aircraft and trained pilots were not available until after World War I. The development of appropriate aircraft and suitably trained pilots occurred in the early 1920's when demand for cotton insect control was high in the U.S.A., and control of forest insects, locusts, and crop pests assumed high priority in the U.S.S.R., while aerial fertilization and seeding began to be demanded in New Zealand.

The first use of aircraft for pest control in the U.S.A. is documented in an article in The National Geographic Magazine of March 1922 (ref. 3) which told of the use of a military observation airplane, a Curtiss JN6, for dusting pests on catalpa trees by Dr. Houser and others at the Ohio Agricultural Experiment Station in 1921. Lead arsenate dust was distributed from the plane by opening a bag and allowing its contents to fall through a hole in the deck of the rear, or observation, cockpit (ref. 4). This early work was done with aircraft, pilot, and crew borrowed from the U.S. Air Service at Dayton, Ohio. Later, a dust hopper was placed on the outside of the aircraft. An observer stood in the rear cockpit and cranked the agitator to distribute the dust more evenly.

In early July of 1922 an outbreak of cotton-leaf worm in several southeastern states of the U.S.A. provided a relatively easily monitored and controlled insect which could be used for judging the efficacy of aerial application. Again the military air service was called in to provide aircraft and several types of hopper designs were developed by personnel of the Delta Cotton Research Station, USDA, then under the direction of Dr. Good. Eventually a self-feeding hopper with a slide-gate metering valve was developed.

The use of aircraft in the U.S.S.R. began with experimental application for controlling a serious locust invasion in 1922 (ref. 5). Spray formulations were used; this may have been the first aerial spray application, since up to that time only dusts were used. Results of the locust control looked good but large spray dosages were reported. The aircraft were small, large areas needed treatment, and the work progressed very slowly. One airplane could only cover 4-5 ha (10-12 acres) per hour. Dusting experiments carried out in 1924 were found to permit coverage of much larger areas. Through dusting operations, four U-1 aircraft were able to cover about 11,000 ha (27,000 acres) with arsenical elements for locust control.

Demand for control of the boll weevil throughout the cotton-growing south of the U.S.A. which was met by aerial dusting with calcium arsenate dust, quickly led to the development of an agricultural aircraft application industry. By 1925 about 20,000 ha (50,000 acres) of cotton were dusted in the southeast, and the practice moved rapidly westward to Texas, where 20,000 ha (50,000 acres) of cotton were dusted in 1927.

Chemical application work in U.S.S.R. really got under way with development of the PO-2 aircraft, capable of larger loads and greater reliability. By 1931, 65 aircraft were in use and materials for locust control were applied to 527,000 ha (1.3 million acres), for mosquito control to 2,000 ha (5,000 acres), and for control of psyllae and silkworms to 8,900 ha (22,000 acres).

While suggestions for use of aircraft for forest insect control in the U.S.A. surfaced in 1918, there is no documentary evidence to show that actual forest spraying or dusting was done, either in the U.S.A. or in Canada, on anything but an experimental basis, until after World War II and the discovery of DDT.

Aircraft were used in seeding operations in the U.S.A. as early as 1929. Bates reported that an Eaglerock biplane (Alexander Eaglerock A-2) with a 90 hp engine was used in California to seed rice (ref. 6). The front cockpit was lined with canvas to make a hopper which held 230 kg (500 lbs) of rice. Two spouts or openings were rigged in the bottom of the canvas liner, and a trip device operated by the pilot opened spouts to discharge the seed. This method of seeding rice was immediately accepted and although the number of aircraft used has never been large, aerial seeding is almost universal practice in rice production in California.

New Zealand introduced aerial range seeding in about 1940. Here seed was ejected in the first tests by the simple expedient of inserting a tube 5 cm (2 in) in diameter into the sack of seed and allowing seed to fall out of the bottom of the aircraft. It was found that the flow rate could be altered by changing the angle of the tube in the airstream.

In 1949 New Zealand also began applying various top dressing fertilizers to some of its very hilly grasslands. It was found that by passing granular fertilizer through a 6 mm (1/4 in) screen, a remarkable spreading of the granules occurred even though they were simply dumped out the bottom of a hopper. Commercial acceptance of this operation was immediate. Commercial enterprises found that small, more maneuverable, planes were more practical than larger aircraft for the top dressing operations.

In the U.S.A., while early development of dusting aircraft was taking place in the Southeast, use of spray aircraft in California began in the early 1930's. Impetus for the change was damage caused by dusts which drifted easily. The first regulations regarding residue tolerance on edible farm products has been enacted in 1927 (ref. 7). Later, a specific ordinance aimed at controlling aerial transport or drift of calcium arsenate was enacted in California as the result of milk contamination from dust drifting from tomatoes into nearby hay crops (ref. 8). This act to limit use of dust and spray soon controlled aerial application in California.

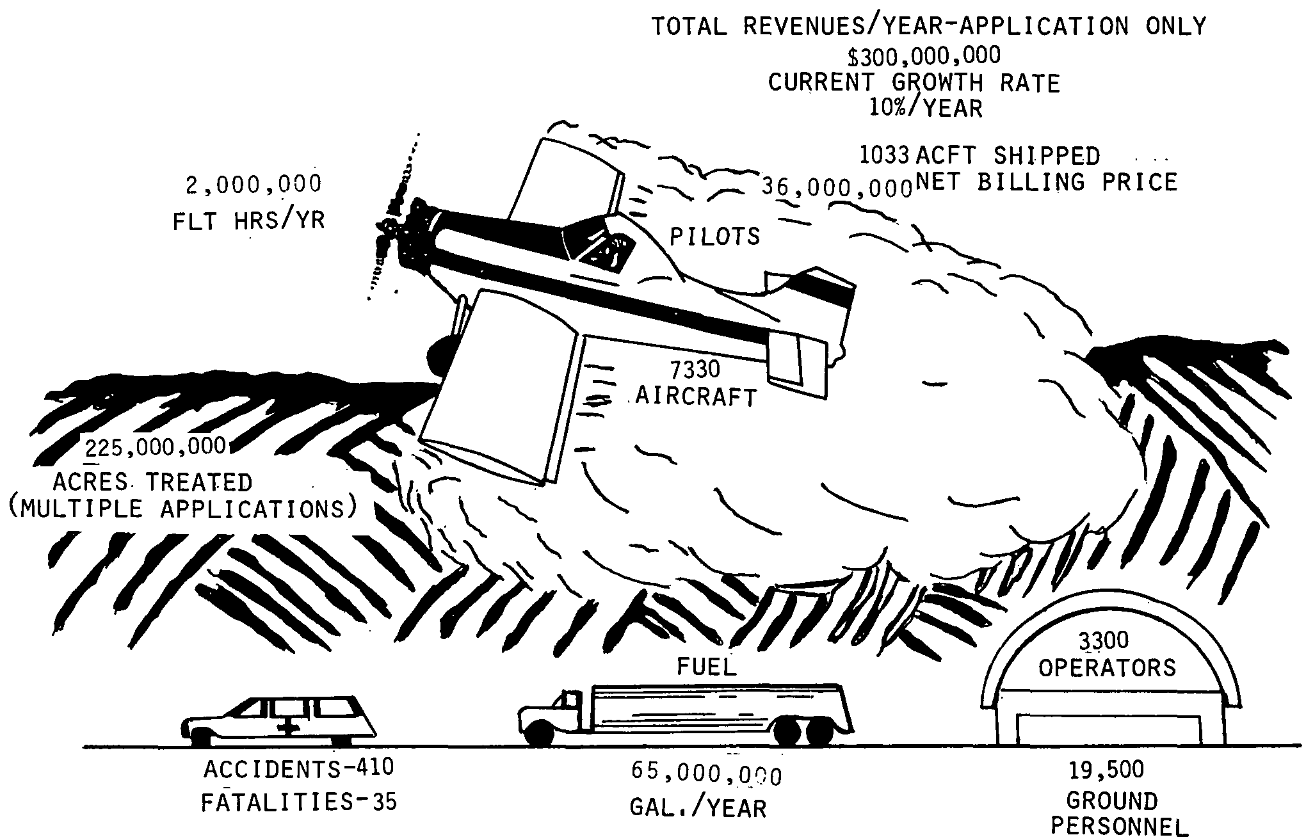
Helicopters were brought into use for air application of agricultural materials in 1945 in England, under the guidance of Dr. Walter E. Rippers. This first work indicated that rotary-wing aircraft could be used for certain types of applications.

With a given installed power, a helicopter cannot lift as much payload as can a fixed-wing aircraft. However, its ability to take off from and land in practically any spot large enough to clear the rotor, to make shorter turns, and to maneuver around rough terrain while applying chemicals, frequently makes up for the low payload. Its ability to carry a spray boom which will cover a wide swath also increases the productivity of a helicopter.

The greatest deterrent to the use of helicopters has been the high initial cost and maintenance required of the cylic-controlled rotor. In recent years the cost has been reduced somewhat, but still accounts for a considerable cost difference between fixed-wing and rotary-wing aircraft. Another deterrent to the use of helicopters is the increased skill necessary for the pilot to operate rotary-winged craft.

The helicopter is used to an advantage especially when materials are delivered to areas of rough terrain where landing strips are lacking, where large obstructions limit the use of fixed-wing aircraft, where fields are small, or where the population is such that it would be unwise to fly

FIGURE 2-1 U.S. AGRICULTURAL AVIATION PROFILE 1976



fixed-wing craft. It has been used effectively for night spraying, frost protection, fruit and vegetable pollination, and in cases where the downwash of the rotor is beneficial for penetration of the spray into the foliage of the plants.

It can be seen that the U.S.A., U.S.S.R., and New Zealand have paralleled the early use of aircraft for agricultural purposes since World War I. It is also quite evident that early uses of aircraft in agriculture, forestry, and the like, were frequently unplanned and too often done on an emergency basis to control unexpected epidemics of insects, pests, and to seed or fertilize in times of unreasonable weather conditions.

Development of Ag-Air Industry (1940-1955)

The general use of available aircraft, which were mainly military planes, and the use of pilots, who were also usually trained by the military, to pursue the application of various kinds of chemicals, seeds, or fertilizers seemed to be the rule in early ag-air operations. Thus, during the first twenty years of use of aircraft in agriculture, little planned development of agricultural aircraft or application equipment took place. Support for agricultural aircraft research in traditional agricultural institutions has been limited. In the U.S.A., for example, research has been accepted and conducted at only a few of the many large agricultural research universities even though the use of aircraft has reached almost every state.

The research that has formed the basis for most aircraft application equipment design and techniques of use has been performed by national government groups charged with responsibility for large-scale control programs for insects and pests as well as for fertilizing and seeding. Work sponsored in the U.S.A. by the Office of Scientific Research and Development during and following World War II set the capability standards of equipment and aircraft that enabled rapid transition to commercial use (ref. 9 & 10). Even earlier government-sponsored research in the U.S.S.R. helped establish the industry there (ref. 5).

It wasn't until well into the 1950's that commercial aircraft specifically designed for application work came into being (ref. 11). Fred Weick designed, built, and tested an aircraft at Texas A & M specifically for agricultural use. His redesign of this plane for the Piper company became the first U.S. commercially produced plane designed primarily for agricultural work.

For over twenty years Norman Akesson and his associates at University of California at Davis have studied aerial dispersal systems and patterns of distribution of sprays and of particulate matter. A systematic approach to design of a dispersal system was conducted by Kenneth Razak. Razak began his research at Wichita University in 1949. This research consisted of a study of boundary-layer and circulation-control, and their effects on lift coefficients through the use of finite-slote suction and blowing, particularly blowing of air over the deflected flaps on airfoils.

In 1958-1959 Razak worked with Akesson at the University of California at Davis. He developed the concept of incorporating the increase of aircraft lift by blowing air over the flaps of an aircraft wing, and the harnessing of this air to also entrain and distribute the material to be applied by the aircraft. The combination of these concepts led to his design and construction of the Distributor Wing Aircraft during the period of 1962-1966.

In an allied activity, Razak has produced a computerized operational analysis of aerial applications by which economic factors, geographic factors, airplane performance and design factors, and biological requirements can be analyzed with regard to their effects on the productivity and profitability of aerial application (ref. 12).

A promosing recent development in the industry is the introduction of turboprop engines which permit much higher power output with lighter installed weight and longer times between overhaul.

Material Dispersal Systems

As suggested earlier in this report, dispersal systems have not progressed as needed. Other than the Distributor Wing Aircraft, most dispersal systems have been developed independent of the airplane. This plane used an auxiliary engine to power the distribution system, and tests indicated that the Distributor Wing reduced streaking and produced a more uniform swath.

Since 1930 a few commercial companies have supplied pumps, nozzles and dry material spreaders, and the other component parts for dispersal systems. Development of dispersal systems has been primarily the responsibility of pilots and operators who have adapted various bits of ground equipment and "field engineered" their design to do the required job.

Shortcomings of early systems were quite apparent. Distribution of materials in a smooth, even pattern has been a major problem. Other problems of importance in the use of some chemicals are wasteful over-spray and damaging drift. In the case of liquid application, small droplets or mist are easily transported by the wind; in some cases the vapor mist may travel great distances and contaminate adjacent crops. Dusts, which were used quite extensively in the past, were also very susceptible to wind transport.

The discontinuance of dusts and the use of granular or prilled materials in place of dusts has overcome much of the dry material drift problem. However, the problem of developing a nozzle for optimum droplet size for wet application is still in the research stage. Optimum droplet size is dependent upon wind speed, aircraft application speed, humidity of the air, height of release above the target, and many other variables.

2.2 HISTORY OF REMOTE SENSING

Prior to 1965, imaging activities were called aerial photography because the sensors were cameras with one kind of film (most often black and white) and the platforms were nearly always aircraft. Since 1965, the term "remote sensing" has applied to imaging the earth's surface from aircraft and space platforms with sensors that "see" within and beyond the range of human vision.

Early Developments in Aerial Photography

Earliest experiments with cameras in lofty places included the first photographs taken from balloons in the 1840's, kites with cameras in the 1880's, use of pigeons with light weight (70 grams) automatic cameras in 1903-1909, and the first aerial photography from an airplane by Wilbur Wright in 1909 (ref. 13, 14, & 15).

Military aerial reconnaissance began in 1914 at Langley Field, Virginia (ref. 13, p. 32), and aircraft were used for conducting surveys of insect damage, spotting forest fires, and aerial mapping of forest land as early as 1921 (ref. 16). Although this report does not concern itself with specific military activities, since World War II the technology which has trickled down to an unclassified status for commercial and scientific use continues to keep the user community looking to the military for possible hardware "plums" that might drop from the sky (e.g., the U-2 aircraft).

Other such "plums" from the military which have been made available to civilian use of remote sensing in agriculture include converted military aircraft, aerial cameras, SLAR (side looking airborne radar), thermal scanners, and even color infrared film, originally called camoflage detection film invented in 1942.

Aerial Photography (Remote Sensing) 1930-1965

Historically, remote sensing of agriculture in the U.S. dates to the 1930's for aircraft applications. Initial government users of aerial photography were the U.S. Department of Agriculture's Agricultural Stabilization and Conservation Service (ASCS) and the U.S. Forest Service. ASCS, originally the Agricultural Adjustment Administration, began systematically photographing farm and ranch lands over the entire U.S. at standardized map scales of 1:20,000, with quality controlled black and white 22.8 X 22.8 cm (9 in X 9 in) photographic prints. Aerial photographic coverage is still gathered at the county level at a scale which provides 5.44 km (3.4 miles) on each side of each 22.8 X 22.8 cm (9 in X 9 in) image. As a consequence of the large map scale and the requirement of steroscopy (photos taken with 60% overlap to provide three dimensional viewing), hundreds of images are required to produce county-wide coverage.

The ASCS photographs, updated every five years, continue to be the base by which the USCA measures and controls specific crop acreages. Furthermore, ASCS aerial photography has become so established in an operational sense that it is often referred to as conventional aerial photography.

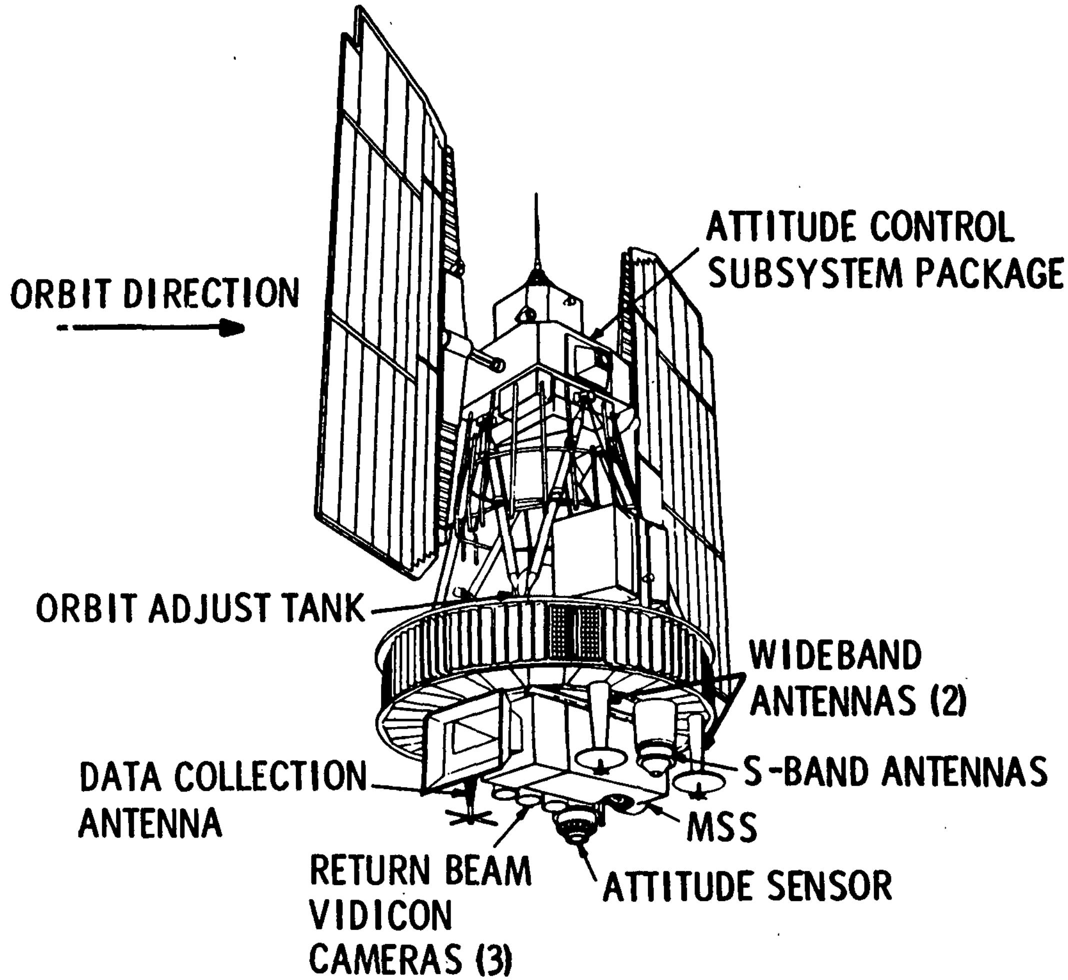


FIGURE 2-2 LANDSAT

The Forest Service began surveying its forest reserves by aerial photography in the 1930's. The U.S. Geological Survey and Tennessee Valley Authority during the same period started their topographic (contour) mapping programs using stereoscopic overlapping aerial photography as well.

Commercial aerial photography, begun in the 1930's as a spin off from the military, became a major contributor to civil engineering and the ASCS and Forest Service. Widely used commercial aerial photography consisted of surveys for highway construction, building and recreational development, mineral exploration, and crop surveys.

NASA's Earth Resources Aircraft Program

NASA's Earth Resources Aircraft Program, centered at the Manned Spacecraft Center (Johnson Spacecraft Center) in Houston, Texas, began about 1965 and was responsible for introducing the exotic forms of remote sensing technology to a wide-range user community of earth and social scientists. The program included studies in the applications of color infrared film, comparisons between film types, and spectral reflectance studies. Between 1965 and 1970 studies were made of applications of multispectral photography to geography, geology, agriculture, forestry, hydrology, oceanography and to sensor studies. Investigations in thermal, passive microwave, and active microwave (RADAR) were also a major part of the Earth Resources Aircraft Program.

In the late 1960's some 289 Earth Resources test sites were scattered over much of the U.S. with NASA agricultural test sites at Lafayette, Indiana; Westlaco, Texas; Davis, California; and Garden City, Kansas. Forest and range sites were at Bucks Lake, Harvey Valley, and the San Pablo Reservoir in California. Among the results of the studies were feasibility summaries of specific land uses and resources which could be identified on the imagery at map scales of 1:10,000; 1:30,000; and 1:1 million for each test site (ref. 17).

During the late 1960's and early 1970's, the NASA Earth Resources Aircraft Program through its experiments in sensor applications and feasibility studies thus opened the way toward the applications of remote sensing technology to earth resources from space.

Remote Sensing from Space

"Contrary to popular belief, remote sensing by rocket is not new" (ref. 13, p. 43). As early as 1907-1912, Alfred Maul developed a gyroscopically stabilized camera which was rocketed to an altitude of almost 800 meters (2,600 feet) (ref. 18). Although such experiments ultimately led to gyrostabilized cameras for today's reconnaissance cameras, a long term hiatus existed until 1946 when space photographs were taken from V-2 rockets launched at White Sands, New Mexico. In 1947, space probes made a quantum jump with the launch of Sputnik I, and within five years both man and machine and terrain photography (no longer aerial) made a similar quantum jump from aircraft to spacecraft as camera carrying vehicles.

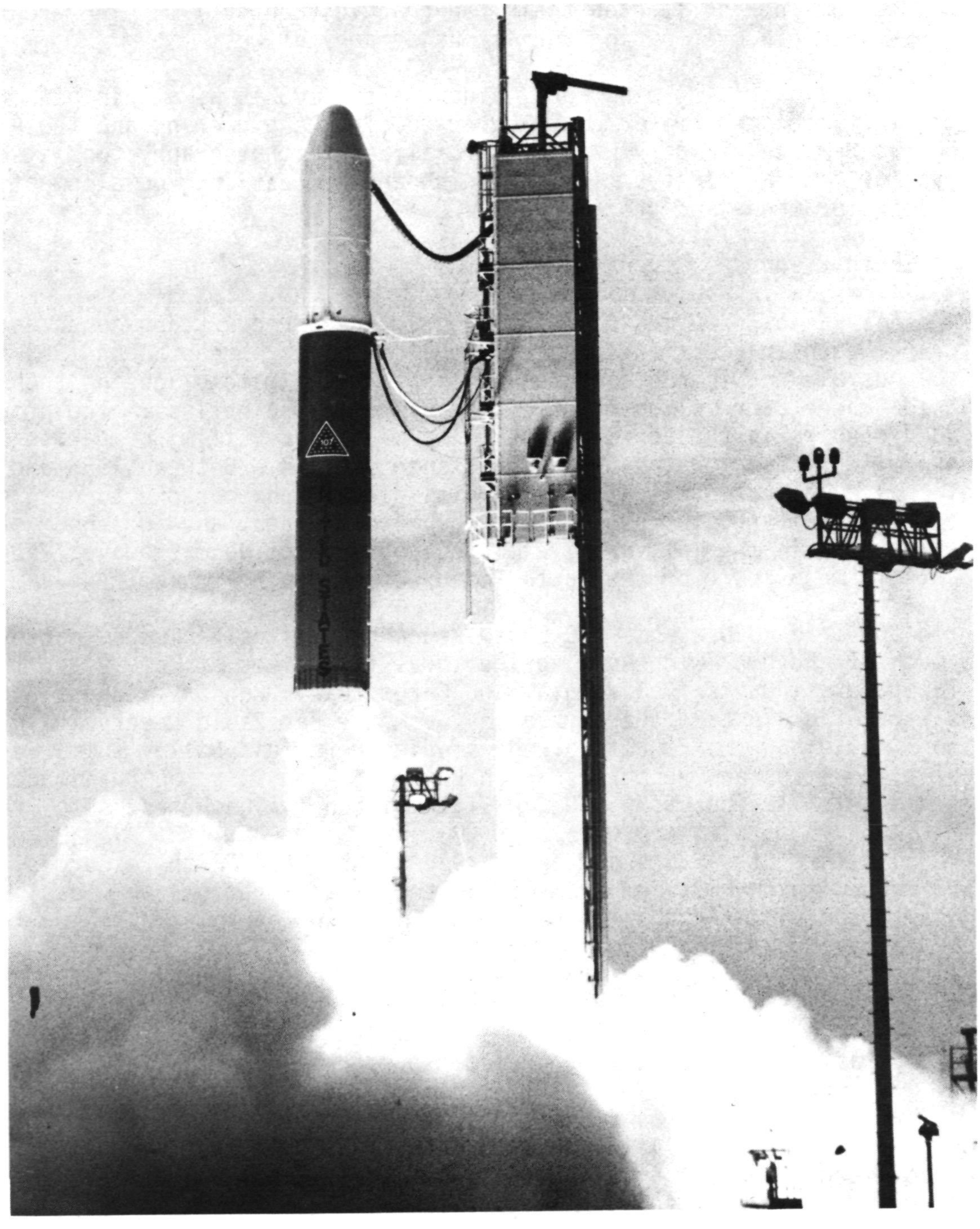


FIGURE 2-3 LAUNCH OF LANDSAT II

NASA's Meteorological Satellites 1953-1973

NASA's experimentation with meteorological satellites began with the Nimbus program in 1958. Designed as a series of test platforms for a variety of remote sensing sensors, Nimbus satellites (five to date) have carried infrared spectrometers, ultraviolet spectrometers, cloud-top altitude radiometers and other radiometric equipment to earth-orbiting altitudes of 1,110 km (666+ miles).

Systematic earth observations aimed at meteorological applications came in 1960 with the launch of Tiros I. For the next six years ten satellites in the Tiros program with their TV sensors and radiometers imaged the earth's atmosphere from an altitude of 1,300 km (780 miles). Between 1966 and 1973, the subsequent ESSA 2-9, Tiros-M and ITOS A-G meteorological satellites with vidicon cameras and automatic picture transmission became operational under the direction of NOAA. To date these have been the only operational (non-experimental) satellites in remote sensing (ref. 19, p. 583). Chapter 6 will specifically cover some of the more recent operational satellites aimed at remotely sensing meteorological conditions on a global scale.

NASA's Manned Spacecraft Program

Remote sensing of earth resources from manned satellites came in 1961 with Mercury program - the first manned spacecraft program. The early photography from this program came when the Mercury (MA-4) spacecraft, then unmanned, photographed parts of the earth with 70 mm color imagery. As strange as it seems to those of us with earth resources interests, the pictures were taken by NASA primarily to monitor the spacecraft altitude. However, these and subsequent images from the Mercury program were later interpreted and utilized in geologic applications (ref. 13).

NASA's role in earth observations from spacecraft increased and improved with the Gemini program. The early 70 mm photography in Gemini III, however, was taken with as much aplomb as a group of tourists on a sightseeing adventure. Later photographic experiments were set up by the U.S. Geological Survey with performance specifications and a general plan for repetitive surveys of earth resources (ref. 20). Specifications and planned formal photographic missions set up in Gemini 4 through 7 led to some 1,100 usable worldwide photographs, many of which overlapped to provide wide aerial coverage of the southwestern U.S.A.

The Apollo program of the late 1960's went several steps further. The Apollo-9 Multispectral Terrain Photography Experiment SO-65 was perhaps the most important orbital photographic experiment prior to Landsat. For the first time, participating scientists and engineers were giving in-flight instructions to the astronauts about particular areas and sites to be imaged. Another unique aspect of Apollo 9 was the underflight and ground truth portion of the program which obtained simultaneous imagery and data as the satellite passed overhead. The experiment objective was to test feasibility and value of multispectral photography for earth resources type studies. Four 70 mm Hasselblad cameras, mounted together in the spacecraft, imaged portions of

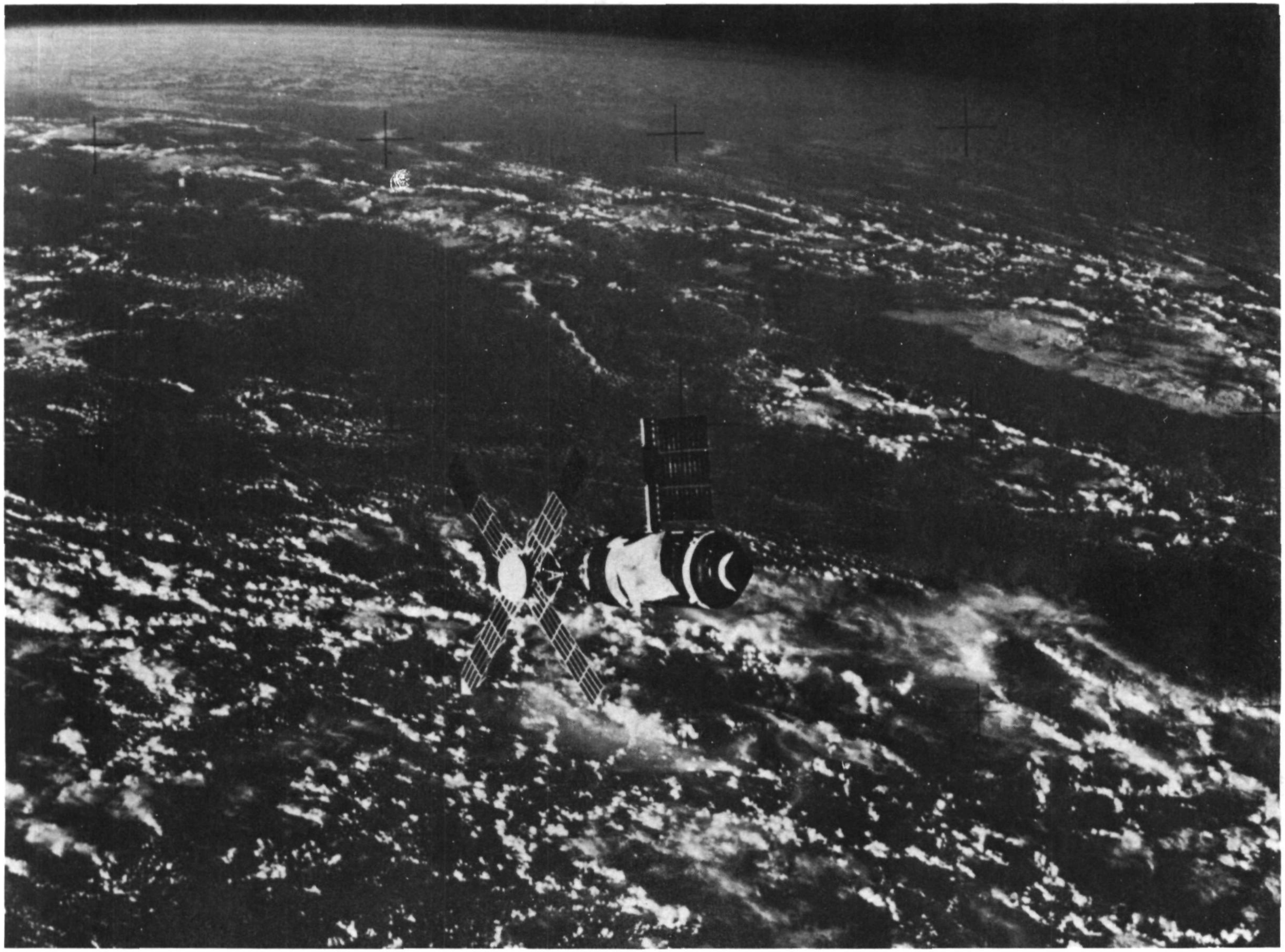


FIGURE 2-4 SKYLAB

the earth simultaneously with four film/filter combinations. Camera A had color infrared film with a yellow filter. Two cameras, B and D, had panchromatic black and white film and were filtered with green filter and red filter respectively. Camera C contained black and white infrared film with a deep red filter (ref. 21). The spectral regions covered in the SO-65 multispectral experiment were selected to stimulate those planned for NASA's Earth Resources Technology Satellites (ERTS) (ref. 13 & 22). The multispectral approach was far superior to the use of a single film and filter because in orbital flight the great range of atmospheric and terrain conditions require more than one spectral observation. Robert Colwell found that the multispectral photos from Apollo-9 permitted crop identifications. These findings thus encouraged plans for similar "multi" type experiments and applications for the Landsat program (ref. 23).

Landsat and Skylab: Developments in this Decade

> "If I had to pick one spacecraft, one space age development, to help save the world, I would pick ERTS and the operational satellites which I believe will be evolved from it in this decade."
>
> Dr. James Fletcher
> NASA Administrator

The most significant advance to date in remote sensing of earth resources and agriculture from space has been the Landsat system. Initially called ERTS (Earth Resources Technology Satellite) the Landsat system began with the launch of ERTS-I (now called Landsat-I) on July 23, 1972. Landsat-II subsequently was launched in January 1975. Placed in a sunsynchronous polar orbit 910 km (570 miles) above the earth's surface, Landsats I and II have imaged selected test sites on a regular basis every 18 days. Because the satellites are in tandem, 9 day repetitive coverage is achieved. Sensor systems aboard Landsat include a three camera Return Beam Vidicon (RBV) and a four channel Multispectral Scanner (MSS). Shortly after launch, the RBV was turned off because of an electrical malfunction. However, excellent image data from the MSS has been telemetered to ground receiving stations in the form of digital data which is processed into photographic imagery (ref. 24). Chapter 6 covers more of the technical details of Landsat and its operation.

Within the first year of operation, Landsat I had given us complete cloud-free coverage of the United States, repetitive cloud-free coverage of large portions of the U.S. for monitoring temporal changes, and cloud-free coverage of large portions of the earth's terrestrial, polar and oceanic regions. For the next three years after launch of Landsat I, hundreds of thousands of high quality MSS images were generated and thousands of reports and maps were produced by the 300+ principal investigators working with NASA on the project. Although Landsat was designed for a one year life expectancy, the system continues to operate and send back data after five years of successful operation (ref. 25).

The Skylab program consisted of three separate manned missions to an earth-orbiting space station. Launched in May 1973, the Skylab structure was housed in a converted section of a Saturn IV B launch vehicle. Although many medical, industrial, and biological experiments were conducted by three groups of astronauts, the experiment which concerns us most in this project was EREP (Earth Resources Experiment Package). The EREP portion of Skylab was the remote sensing of selected test sites on earth from an altitude of 435 km (235 miles). Sensors on board consisted of six multispectral cameras of 150 mm (6 in) focal length, an Earth Terrain Camera with a 460 mm (18 in) focal length, a 13 band multispectral scanner, an infrared spectrometer, an L band radiometer, and a microwave radiometer/scatterometer and altimeter (ref. 26).

Unlike Landsat, Skylab missions had a design life of 28 to 84 days per visit for each of the three visits. As global coverage was never intended in the project, the aerial extent of image coverage was limited to selected passes west to east over the tropics and mid-latitudes. Cylic repetitive coverage at the same sun time could not be accomplished with Skylab. Despite these limitations, Skylab did provide far more spectral information than did Landsat over broad ranges of the electromagnetic spectrum. High quality color and color infrared film, exposed in its high resolution cameras, was exchanged for fresh film and returned to earth by the astronaut crews. Skylab ended early in 1974 and like other NASA projects was experimental not operational.

Conclusion

> "For more than a century, man has been taking aerial photographs of one kind or another from which to inventory certain earth resources. Only within the last decade or so have important developments occurred which promise to make such resource inventories feasible for the first time on a national or global basis. Most of these developments have been in three inter-related areas: (a) improved capabilities of the aerial camera or other remote sensing devices, (b) improved capabilities of the vehicles from which these sensors are operated (ranging from the hovering helicopter to the earth-orbiting spacecraft), and (3) improved capabilities in image analysis by both human and mechanical means" (ref. 1y, p. 28-15).

The history of remote sensing has thus evolved from a group of civilian experimenters attaching cameras to anything that might fly to a military emphasis especially during and since World War II. Today civilian activity is once more important and is dominated by experimentation and application using NASA technology.

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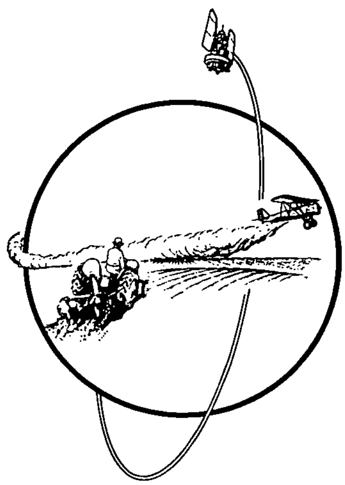

Goals and Objectives of the Study

Program Goal and Objectives

Program Goal

To improve productivity of agriculture through aerospace technology

Study Objectives

- Study possible applications of aerospace technology to agricultural production.

- Recommend to NASA fruitful areas in which to concentrate research and technology

CHAPTER 3

GOALS AND OBJECTIVES OF THE STUDY

The ultimate goal of this study is: TO IMPROVE PRODUCTIVITY OF AGRICULTURE THROUGH AEROSPACE TECHNOLOGY.

Agriculture is defined as the production of food, fiber, fuel, medicinals and other chemicals from living organisms.

To Improve Productivity is a goal which may be accomplished in a number of ways. Improving productivity may mean:

Raising the quality of the product

Increasing the yield per unit of growing area

Increasing cost-effectiveness of production

Increasing energy-effectiveness of production

Increasing the production base, e.g., bringing more land (possibly marginal land) into production

Minimizing social and ecological disruption resulting from agricultural production

The present study assumes each of these six definitions of improved productivity as part of the primary goal of the system of agricultural production.

A direct study goal results from the desire to conduct more than just an abstract exercise. This goal is that the study produce recommendations of the most fruitful areas for NASA to conduct research and to develop technology to further the ultimate goal of improving productivity of agriculture through aerospace technology.

In order to accomplish this direct goal, it is necessary to consider various possible applications of aerospace technology to improving agricultural production and to evaluate the worth of each of these objectives. The criteria by which this evaluation may be carried out are the various definitions of improved production - i.e., higher quality products, more yield per unit area, more cost-effective, more energy-effective, ability to use marginal land, and very importantly, the social-cultural-ecological impact.

Chapter 4 discusses, in detail, the criteria for establishing priorties for forming the final recommendations. Chapter 7 expands on the socio-physical environment and the impact of applying technology to agriculture.

STUDY OBJECTIVES

- Apply Technology to Monitor Environment and Resources of Earth
- Apply Technology to Intervene Directly In Agricultural Production, Including Aerial Application
- Apply Technology to Agri-Business and Support Services for Agriculture

CRITERIA FOR EVALUATING AEROSPACE TECHNOLOGY APPLICATION TO AGRICULTURE

- ▶ Higher Quality of Product
- ▶ Increased Yield Per Ground Area
- ▶ More Cost-Effective Production
- ▶ Ability to Use Marginal Land
- ▶ Minimum Social-Cultural-Ecological Impact

The objectives -- the possible applications of technology to agricultural production -- are listed below and are discussed in some detail in Chapters 5 and 6.

1. Apply technology to intervene directly in agricultural production, including improvement of aerial application. This objective includes:

   a. Planting of crops, including soil preparation and seeding, also stocking of fish and other marine life.

   b. Promoting growth which includes timely application of fertilizer and control of diseases, weeds, and pests.

   c. Ripening and harvesting, including ripening, defoliation, drying harvesting. Also included are location and catching of marine life and preparation of livestock for slaughter.

2. Apply technology to agri-business (support services for agriculture). This objective includes:

   a. Market analysis, planning, price supports.

   b. Chemical industry which develops, tests certifies, and produces pesticides, nutrients, and herbicides.

   c. Hybrid seed development and production.

   d. Physical equipment, including ground equipment and aircraft. Aircraft R & T have the goals of:

      1. Improved aerodynamic and structural performance

      2. Increased distribution system accuracy

      3. Increased system efficiency and safety

      4. Improved environmental safeguards

      5. Reduced energy consumption

   e. Processing, transportation and storage of products.

3. Apply technology to monitor and understand (and, in some cases, control) the environment and resources of the earth. This objective includes:

   a. Land use inventory and crop monitoring including monitoring of pests and diseases.

b. Monitoring environmental quality, including water and air pollution, soil erosion, and prediction of water availablity from monitoring snow cover.

c. Improvement of application of technology to weather forecasting and to weather modification, and to climatic trend forecasting.

d. Improvement in diffemination of information.

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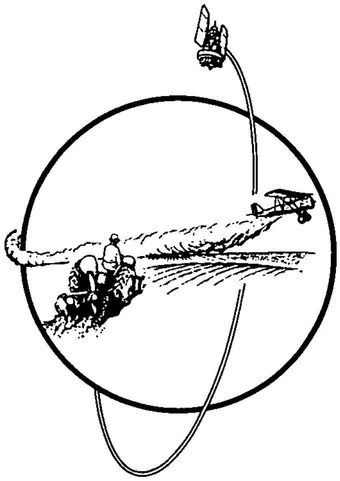

Criteria for Establishing Priorities

CHAPTER 4

CONSIDERATIONS AND CRITERIA FOR ESTABLISHING PRIORITIES

4.1 INTRODUCTION

In the previous chapter the goal of the study was stated: Improve Productivity of Agriculture Through Aerospace Technology. Dr. Bruce Holmes, technical advisor to the design study team, stated this goal more specifically: "Based on current and projected technology (in aeronautics and space) what long term impact might NASA have on the entire agriculture system?"

The design team recognized early in the study that a statement of goals and objectives does not completely define a problem. There are limitations or boundaries which will constrain solutions which might be proposed. These limiting conditions become criteria by which possible solutions may be judged and ranked, and together with the goals and objectives, these criteria define the problem.

Because of the importance and global import of increasing agricultural production, the limitations are defined by the political, social/cultural, religious, and economic responses. In addition, because of the extent of the problem, energy availability and ecological impacts also limit the approaches.

In order to formulate criteria for judging means to attain the goals, five aspects of the boundaries of the problem are examined in this chapter. These aspects are:

1. Consumption of energy
2. Economics and cost-effectiveness
3. Social and cultural disorganization produced
4. Ecological considerations
5. Demographic considerations

4.2 CONSUMPTION OF ENERGY IN AGRICULTURE

Historical Background

While virtually all energy we use is derived from the sun, growing of green plants represents the only renewable source of stored solar energy widely available. Plants collect and store solar energy in chemical form which is recoverable by man by consuming the plants as food (or eating animals which have consumed plants as food) or by burning plants (such as trees) or plant products (such as alcohol) as fuel.

Man first evolved as a hunter and gatherer of food. About 10,000 years ago the first great technological revolution in agriculture occurred with the domestication of plants and animals. In these early societies, the solar-chemical energy cycle is complete and self-contained. Energy for tilling, planting, cultivating, and harvesting comes directly from food consumption through the muscle power of humans and draft animals. Power for food processing also comes from muscles and energy for cooking is obtained by burning agricultural products. The cycle is completed when crop residue and manure fertilize the soil in preparation for the next planting.

The second great revolution in agriculture occurred during the Middle Ages in Europe following the adoption of the horseshoe and horse collar, the mold board plow, the watermill and windmill, and crop rotation. This second revolution, while dependent upon a primitive iron technology, was still based upon a renewable energy cycle. Iron was smelted by charcoal and the drain upon non-renewable natural resources, principally iron ore, was insignificant in terms of the total world supply.

The invention of the engine changed all that. Windmills and watermills gave way to steam engines which made possible steam railroads and steamboats. Forests of northern Europe were soon depleted to make charcoal for iron and steel production and to provide fuel for engines. Coal, a nonrenewable resource, became the basic energy source for the manufacture and operation of these engines. The renewable energy cycle had been broken, particularly in the handling of food. Internal combustion engines and electric motors began the shift of food production to a nonrenewable cycle as well. Oil and natural gas became the main energy source. More recently, fertilizers and other chemicals dependent upon natural gas and petroleum have increased the dependence upon nonrenewable energy. In the United States today, it has been estimated (ref. 1) that over seven units of fossil fuel energy are needed to provide one unit of consumed food energy. This situation has been vividly stated by H. T. Odum (ref. 2), "Industrial man no longer eats potatoes made from solar energy, now he eats potatoes made from oil."

Justus von Liebig developed the idea that the numbers in any dynamic system are limited by whatever essential factor is in shortest supply. This principle is stated as the law of the minimum. It may be that the factor in shortest supply in the coming era will be energy. With the world supply of stored energy in fossil fuels endangered by an ever growing population and wasteful consumption practices, efficiency of the energy cycle in production and processing of food and fiber assumes vital importance. A balance between food production and available energy must be reached. In the long run ways must be found to eliminate fossil fuel energy in the food energy.

The magnitude of the problem can be illustrated by noting that the present world population is about 4 billion and is projected to be near 7 billion by the turn of the century (ref. 3). The majority of the world population lives on

2100 kilocalories of food per day (ref. 4), and, in the United States, about 3300 kilocalories per day (ref. 3). To maintain present levels of food consumption even without improving the lot of those in food-poor countries, world food production must increase according to world population growth.

In the problem of progressing from the present nonrenewable energy cycle to a new renewable energy cycle the mathematics of fossil fuel consumption is not the only consideration. The reluctance of Americans to accept what appears to them to be a lowering of their standard of living is a major obstacle to reduction of fossil fuel energy use. Another obstacle is the desire of much of the rest of the world to adopt the American standard of living. A specific example is the emergence of married women in the work force which conflicts with attempts to reduce energy consumption in processing and packing of convenience foods. It will be difficult to define a transition energy policy which is workable in our evolving society.

The Food Energy Cycle

Some insight into how the energy cycle can be improved may be gained by examining the flow of solar and fossil fuel energy into the food and fiber production chain. Fortunately, basic data regarding this energy have been collected from a number of sources (ref. 1 & 5). These data indicate that for each unit of food energy consumed in the United States 28,000 units of solar energy reach the earth's outer atmosphere. Where all this solar energy goes and how it is used is summarized in Figures 4-1 and 4-2. The figures also show where fossil fuel energy is added to the food chain. The numbers used here may differ from those in other references, including some of those listed below. For our purposes, actual numbers are not important since the basic pattern of energy flow is not questioned.

Modern agriculture is distinguished by the high rate of capture of solar energy by plants, shown as 16 units in Figures 4-1 and 4-2. This capture represents an average of about 0.2% of the available photosynthetic energy. Actual capture will depend upon the crop and upon the intensity of farming. It is estimated that grazing lands capture about 0.1% if the available photosynthetic energy, forests 0.2% and tilled land 1% (ref. 6). The high rate for tilled land has been achieved by heavy expenditures of fossil fuel energy in the production process. For example, Figure 4-3 (ref. 5) shows fossil fuel expenditure to achieve high levels of solar energy captured for corn. Rates of capture of several other important crops are given in reference 4. Since primitive agriculture produces rates of capture similar to that for grazing land, about 0.1%, the importance of the fossil fuel input to achieve production levels to meet demands of present population and nutritional levels is apparent.

Alternatives to Energy Intensive Agriculture

Those who are concerned about adverse effects of energy intensive agriculture have looked for alternate approaches to achieve increased production. One hope is to bring more land into production. The FAO estimates (ref. 4) that 11% of the world land area (1.5 billion hectares) is suitable for intensive cultivation and most of this is in use. Another 22% (3.0 billion hectares)

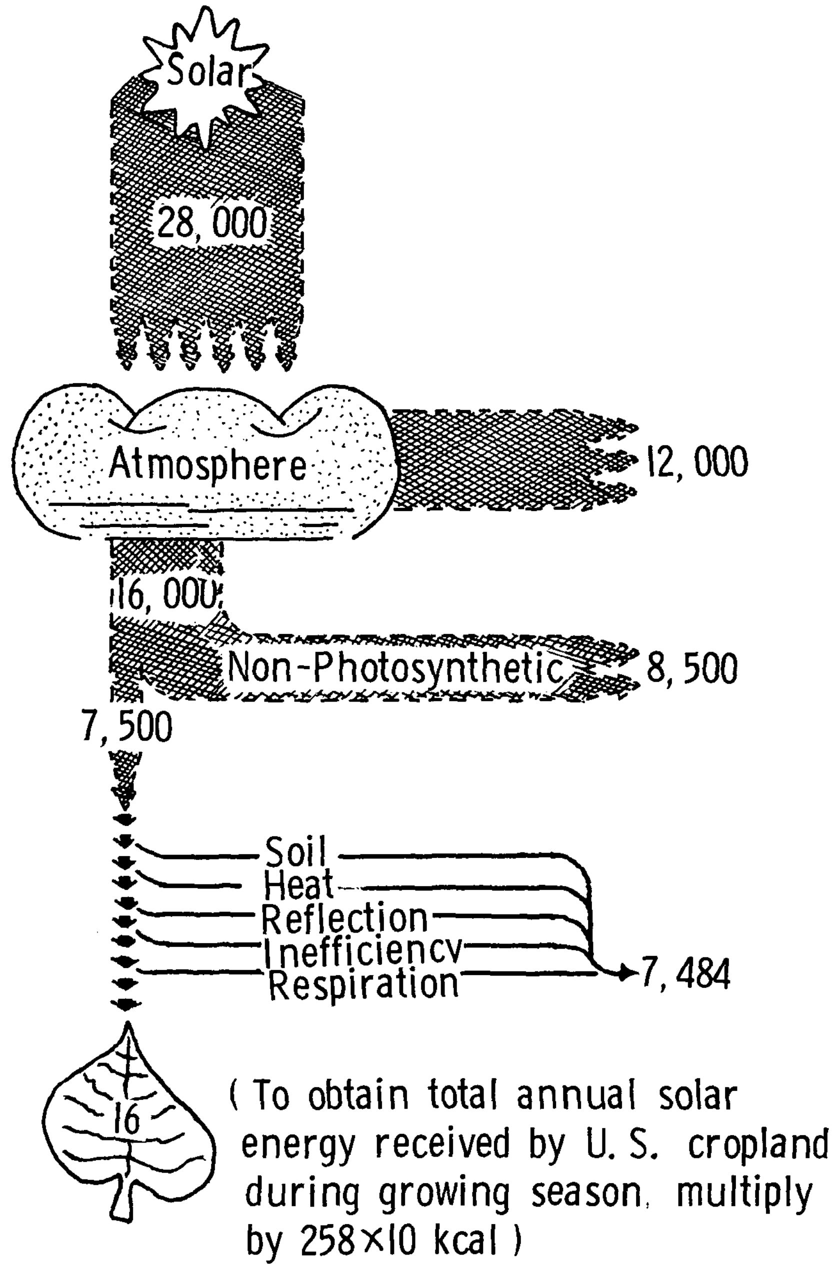

FIGURE. 4-1 FLOW OF ENERGY FROM SUN TO PLANTS

currently is in pastures, ranges and meadows, 30% (4.1 billion hectares) in forests, and the remaining 37% is too cold, too dry or too steep for agricultural production. It has been suggested that the amount of cultivated land could be doubled by using irrigation and other methods, however, to bring marginal land into production would require enormous expenditures of fossil fuel energy, even more than is used for intensive farming of existing arable land (ref. 6). The Malthusian doctrine (see section 4.6) appears inescapable now that the supply of arable land appears to be used near its limit.

Another suggestion is to change eating habits to depend more upon vegetable protein and less upon animal protein. It may be seen in Figure 4-2 that 10.3 units of energy in animal feed is required to produce 0.38 units of food energy. It is suggested that the plant food be used directly thus bypassing the energy cost of animal food production. Quite aside from the socio-cultural problem of inducing consumers to eat more beans and less steak are other considerations. For one, the energy loss is not as great as it first appears. Much animal feed is in a form not usable by humans and much of that is grown on land not suitable for cultivation. For example, over half the livestock protein is produced from pasture and rangeland not suitable for producing food for man (ref. 6). In the production of milk, about 31% of the vegetable protein consumed by the cows is converted into protein in the milk. If efficiency of conversion is based on the animal's intake which is usable by man, then the efficiency is more than 60%.

The next most efficient converters are eggs (27%) and broiler chickens (18%). This compares with catfish (11%), pork (9%) and beef (6%). However, chickens, catfish and pork depend heavily on feed also usable by humans (ref. 4).

It should also be noted that animal protein is of higher nutrition value than vegetable protein because of certain balances in amino acids (ref. 4). Clearly animal food is less energy efficient than plant food but the differences are less than often claimed. Social costs may be the controlling factor. Need for high quality protein and demand for highly palatable food will likely keep demand for animal food products high, however, some shift from more costly animal products is possible.

It would appear, for the next few decades at least, that population pressures will demand continued use and expansion of energy intensive agriculture just to maintain present levels of per capita food consumption. Nevertheless, there must be a major effort to reduce dependence upon fossil fuels and to increase the ratio of solar energy captured by plants to the input of fossil fuel energy. Fossil fuel energy inputs, shown in Figure 4-2, have been restated in Table 4-1.

Conservation of Fossil Fuels

From Table 4-1 it is clear that by far the most fossil fuel energy is used in the processing of food rather than in its production. Food preparation, i.e., cooking, requires large amounts. Here, then, are the most promising areas

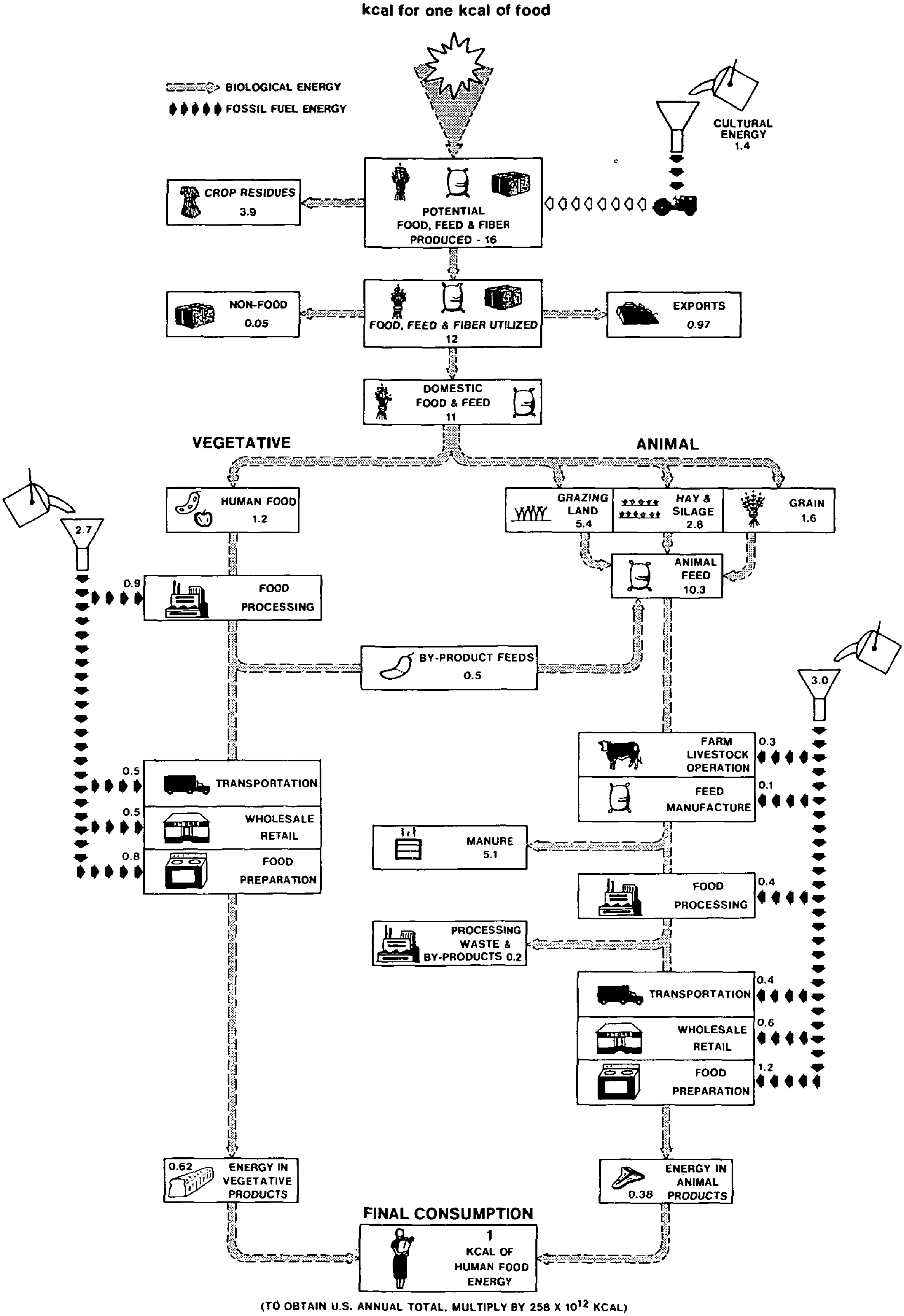

FIGURE 4-2 ENERGY IN U.S. PRODUCED FOOD

TABLE 4-1

UNITS OF FOSSIL FUEL ENERGY TO PRODUCE ONE UNIT
OF CONSUMED FOOD ENERGY - UNITED STATES

Production (1.4 units)	
0.03	Manufacturing Machinery
0.09	Drying
0.14	Irrigation
0.26	Field Operation
0.53	Chemicals
0.35	Other

Processing (5.7 units)

Animal		Vegetable	
0.3	Farm livestock		
0.1	Feed manufacturing		
0.4	Food processing	0.9	Food processing
0.4	Transportation	0.5	Transportation
0.6	Wholesale-Rental	0.5	Wholesale-Rental
1.2	Preparation	0.8	Preparation

for the conservation of energy and for shifting from fossil fuel to renewable fuels. Agriculture, like any other industry, is dependent largely upon national energy policies which encourage conservation and which develop alternative fuels for power production.

This report focuses primarily on the production of agricultural products, specifically upon field operations and chemicals. Field operations account for only 0.26 units (out of 7.1 units) of fossil energy used. Since field operations require a portable energy source and the only readily avilable portable fuels are based upon petroleum and natural gas, there can be only limited immediate reduction in the use of fossil fuels. More efficient machines can be built; more efficient techniques of farming can be utilized; but significant gains are not to be expected immediately. The inescapable conclusion is that we will be dependent upon fossil fuels for field operations for many years to come.

Alternative fuels have been proposed. Alcohol and methane produced from agricultural products have been mentioned, but it is unlikely that these products, which are valuable as soil conditioners and fertilizers as well as feed and food, can be spared in the quantities needed. Hydrogen has also been

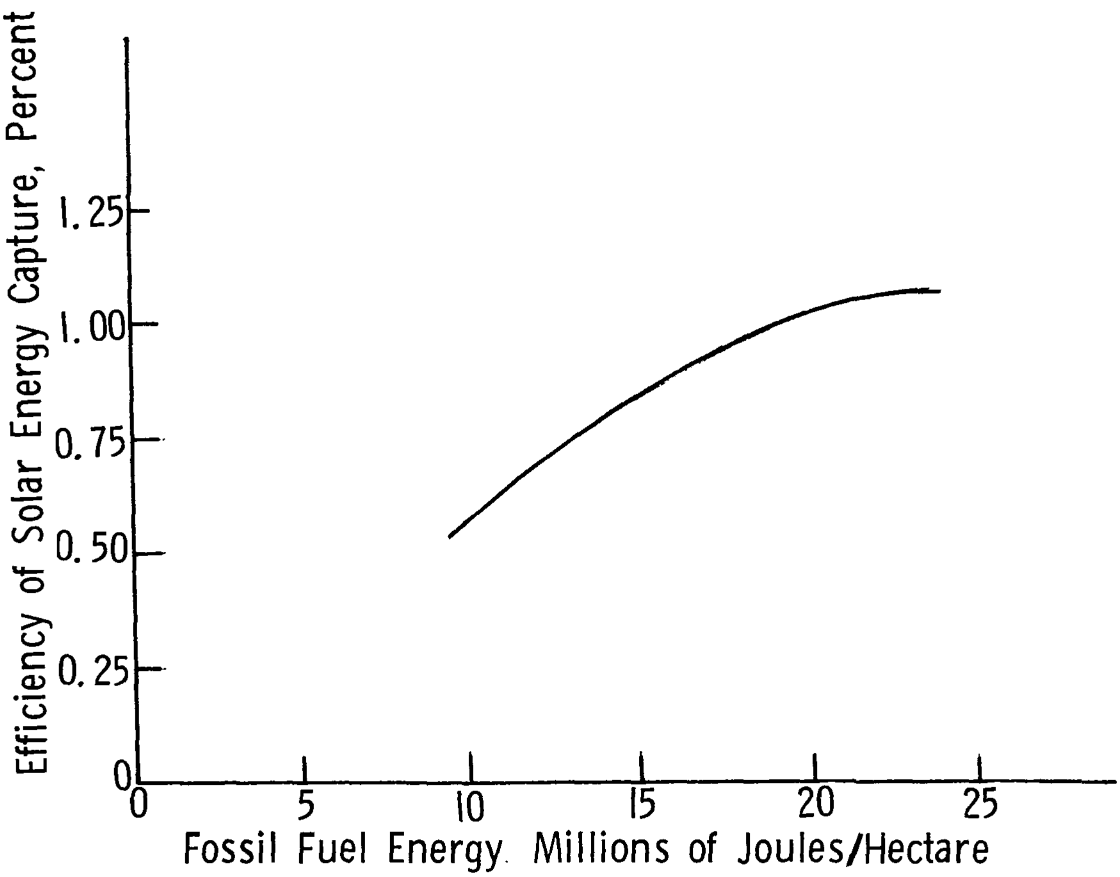

FIGURE. 4-3 ENERGY RELATIONSHIPS FOR U.S. CORN PRODUCTION

mentioned. To use fossil fuels to make hydrogen accomplishes nothing. Some day, if vast quantities of direct solar energy or nuclear energy can be harnessed to produce hydrogen, it may become a practical portable fuel.

The United States uses about 1/3 of the world's production of commercial energy; U.S. agriculture uses 1/40 of the commercial energy for agricultural production (ref. 3). In view of the basic necessity for food and the large production for both domestic consumption and export, the agricultural sector does not appear to be more wasteful of energy than other sectors. This does not obviate the need for conservation, however. One of the more important uses of energy in agriculture is production of fertilizer. Nitrogen fertilizer requires 85% of all energy used in production of fertilizers in the U.S. Most of this energy comes from natural gas; 2% of the natural gas produced in the U.S. is used to manufacture nitrogen fertilizers. Manufacture of all fertilizers requires 1% of our total energy production and pesticides require another 1/10%. In return it is estimated that fertilizers contribute a third to our total food production and pesticides a varying amount that is hard to estimate, but is known to be significant (ref. 5).

Other energy uses in agriculture such as irrigation and drying contribute to overall increases in solar energy capture. They add to other factors which make American agriculture up to 20 times more productive than primitive agricultures. The price is fossil fuel energy in consumption which is required for productivity levels necessary to maintain adequate nutritional levels for an expanding population. This level of consumption cannot go on indefinitely.

Criteria for Energy Efficiency

The long range goal must include the eventual independence of agricultural production from fossil fuel energy input. The prospect for the next few decades, however, is a greater dependence. Population pressures will permit no other solution, assuming worldwide famine is an unacceptable solution. Thus, while we may work toward decreased dependence upon fossil fuel energy a more realistic goal for the immediate future is to seek ways to increase the ratio of output of food energy (captured solar energy) to the input of fossil fuel energy in food production, while maintaining production levels consistent with population growth. This statement is the prime criterion for comparing energy efficiencies of alternate agricultural systems.

If aerospace technology can improve this ratio of captured solar energy while maintaining adequate production levels it should be judged superior to alternate technologies in an energy sense. Other considerations may require the adoption of aerospace technology to increase food production even when energy efficiency is not increased. This possibility must be recognized and energy costs must be understood and widely known when such choices are made.

Aerospace Technologies

There are a number of aerospace technologies which have potential to improve energy utilization in agriculture.

(1) Aviation Technology. The basic mission of agricultural aviation is to intervene in plant culture to bring about greater yields. Higher yields means that plants have been induced to capture more solar energy by properly preparing the soil, planting, fertilizing, irrigating, removing weeds, controlling disease and pests; and spraying and spreading chemical fertilizers and pesticides, by seeding, planting and stocking, by weather modification (e.g., cloud seeding) and fire control. Aircraft have potential not only to improve the solar/fossil fuel energy ratio in agricultural production but also to decrease the absolute expenditure of fossil fuel energy by more effective aerial applications.

(2) Space Technology. Intervention in plant culture can be made more energy efficient by exploiting remote sensing and related informational system technologies (ref. 7). Remote sensing can also aid in the exploration for and monitoring of fossil fuel energy resources such as oil and coal and thereby contribute to a plan for optimum utilization of these resources.

In general, space technology can contribute immeasurably to the task of measuring the earth's capacity to sustain human life, to know in advance the earth's production of food, to know how much fresh water, fossil fuel, mineral resources, and land are available and how best to utilize them.

(3) Alternative Energy Technologies.

i. Wind Energy. Aerospace technology is currently being utilized to develop wind energy conversion systems. There are two main approaches to the problem. One effort is to supply energy directly into the national electric power grid. The second effort is to develop smaller units to be used by isolated (usually rural) installations in developing countries.

Larger units will probably be operated by utility companies; much interest is being expressed by municipally-owned and cooperative utilities. They will be operated as fuel-saver units rather than as replacement for generating capacity, i.e., when the wind is blowing, electricity will be generated by the wind turbines and fuel-powered units may be cut back or closed down. Combinations of wind power with hydro-plants are particularly attractive. Addition of wind turbines to a hydro-electric system has the same effect as increasing reservoir size; when the wind is blowing, less water flows through the penstocks.

To operate as part of the national power grid which distributes energy to chemical manufacturers as well as to meet U.S. farm needs, the electricity generated must be 60-cycle power. There are a variety of ways of producing synchronous power. ERDA is concentrating on pitch-controlled constant-speed wind turbines driving synchronous generators. A NASA designed mod-0 (100 kw) machine is operating at Sandusky, Ohio and similar machines are being installed at selected locations around the country to be operated by utility companies. Sandia Labs are developing Darrieus-type rotors which drive induction generators. Operating at near constant speed, these induction machines will provide synchronous power. Various other projects to produce synchronous power from variable speed turbines are under way (including frequency-modulated generators at Oklahoma State University, and induction machines with variable external resistance at Wichita State University).

Units not producing synchronous power are usually smaller. For use in isolated locations or in developing countries, they probably should include energy storage, such as batteries or pumped water storage. A particularly suitable application is that of pumping water for irrigation; when the wind blows, the water is pumped.

Technology for the smaller units is available today, although improvements in turbine design and storage systems can still be made. The large synchronous system will probably not make significant contributions to the total energy requirements of the U.S. until the 1990-2000 period.

ii. Solar Energy Collectors. The space program has used solar energy collectors to power on-board systems of many satellites including the Skylab manned space station. Technology developed here has been proposed for use in providing electrical power on the earth. One proposal is to deploy a large array of solar cells to collect solar energy and convert it to microwave energy which would be beamed to receiving stations on earth where it would be converted to 60 cycle electrical energy and distributed via the national electric power grid.

The advantage of solar collectors in space is that there is no cloud cover and night need never come. On the earth, absorption of solar energy and intermittent operation resulting from rotation of the earth are serious limitations. Such devices will probably not be developed until after the year 2000.

iii. Other Aerospace Technologies. Use of hydrogen as a fuel has already been exploited in rocket engine technology. Valuable expertise could be provided if a hydrogen fuel economy becomes a possibility. Knowledge of closed life systems which recycle wastes, such as those in Skylab, may contribute to development of less energy wasteful food cycles and may help in developing alcohol-methane fuel systems using garbage and other agricultural wastes. Tidal and ocean current energy technology may benefit from advances in wind energy technology. Aerospace technology developments in thermal systems may also contribute to extraction of geothermal energy.

4.3 ECONOMICS AND COST-EFFECTIVENESS

Aerospace technology discussed in this report will be evaluated on the basis of economic considerations. Some technologies may be extremely effective in performing a specific task and they may provide socially desirable benefits, but if they are not economically feasible they will probably be rejected.

For example, a particular fertilizer may be effective in stimulating the growth of a crop and it may be exceptionally well suited for aerial application. However, if its cost makes it non-competitive with crops produced by other methods, it is not likely that the fertilizer will be widely used.

There are several concepts from the field of economics that may be useful in evaluating the innovations in ag-air technology discussed in the following chapters.

Micro-economics versus Macro-economics. These concepts are used to distinguish the various types of decision making units. Micro-economics is typically used in discussing decisions that are made by individuals or integral units, while macro-economics is used in the discussion of decisions made by complex units or groups of units or decisions resulting from actions of multiple units.

For example, in creating technology for western developed nations it must be kept in mind that decisions about the use or non-use of pesticides and fertilizers are often made by individual farmers. Farmers also decide whether ground or aerial applications are most appropriate. In contrast, industrial nations with centrally planned economic activities do not permit decisions of this type to be made by individual farmers. Particularly in areas where monocropping practices are widespread, decisions are made that involve entire regions. Problems of drift that would be of great concern to a farmer in the United States would be of little or no concern to a farmer in the Soviet Union.

In third world nations economic decisions are made at both micro and macro levels. Widespread introduction of new technologies may be unrealistic in agrarian societies because peasants on subsistence size plots lack disposable income to purchase necessary materials and services. Decisions to use herbicides or insecticides may need to be made at governmental level. The decision-maker contemplating wide area applications would need to weigh benefits of increased production against the impact on the balance of payments.

Cost Effectiveness. Cost effectiveness is defined by the economist as the least-cost combination of economic inputs to accomplish desired objectives or benefits. This concept is used when alternative methods or systems are being evaluated. To be applied effectively, the level of benefits must be held constant, the benefits must be defined precisely, and if possible, they should be quantified. The system that accomplishes the desired objective at the lowest cost, all other factors being equal, is regarded as most cost effective.

For example, if an agricultural decision-maker needs infrared color prints with resolution of 3-5 meters at nine-day intervals to provide early warning of crop stress he will want to know which of the several camera-platform systems available cost the least. This factor can be reduced to a dollar figure. He will also want to know which system will be most effective. Effectiveness may be measured in terms of the percentage of the job needed which is completed. The decision maker, knowing the costs and the effectiveness levels of the alternative systems available, can make a more rational decision. A detailed discussion of procedures involved in cost effectiveness studies is presented in chapter 6.

4.4 SOCIAL AND CULTURAL IMPACT

Aerospace technologies discussed in this report will also be evaluated on the basis of social-cultural criteria, such as social values, legal and political implications, and impact of technologies upon social patterns. Where relevant, discussion will center upon agricultural problems of developing countries versus those encountered in modern industrialized countries. What follows are some clarifications of how these socially relevant criteria will be applied to agricultural technology.

The decision to employ potentially harmful technologies, such as pesticides, varies with the level of development, as well as the traditions and values of a given culture. In the modern Western nations, pesticide usage is evaluated in the context of the overall quality of life. For example, production benefits of certain chemicals have been judged unacceptable because of potential environmental damage. Developing nations, when faced with potential widespread hunger due to crop losses to insects, may be unable to afford the luxury of environmental purity.

Legal/political considerations are the processes whereby social values of a culture are legitimized into public policy. In urban-industrialized nations, how, when, and by whom certain agricultural technologies may be applied has been codified in the form of laws and administrative regulations. In less institutionally differentiated nations problems of reaching consensus on legal codes are less complex; however, problems of translating the codes into operating procedures and problems of enforcement are probably more difficult in developing nations than in industrialized societies.

It is well documented that technologies impact upon social structures. This is no less true in an industrialized state than in developing nations. In the United States, for example, cost-effective high technology farming is rapidly displacing the cost-marginal family farm, even though governmental intervention has been attempted to stem the tide against this culturally valued institution.

A developing nation considering widespread application of modern agricultural technologies (such as ag-air and/or fertilizers and herbicides) must consider the potential impact of the technology upon existing social structures. Monocropping and high technology farming, for example, could have the effect of displacing large numbers of otherwise unskilled agricultural workers. This is not to suggest that such practices should not be adopted, rather that the potential impact of each technology must be assessed.

The socially relevant criteria of economics, social values, legal/political systems and social structures will be used in subsequent chapters to evaluate the potential impact of modern agricultural technologies upon the social systems in which they are employed. The criteria will be those of producing minimal social, cultural, political, and economic disruption.

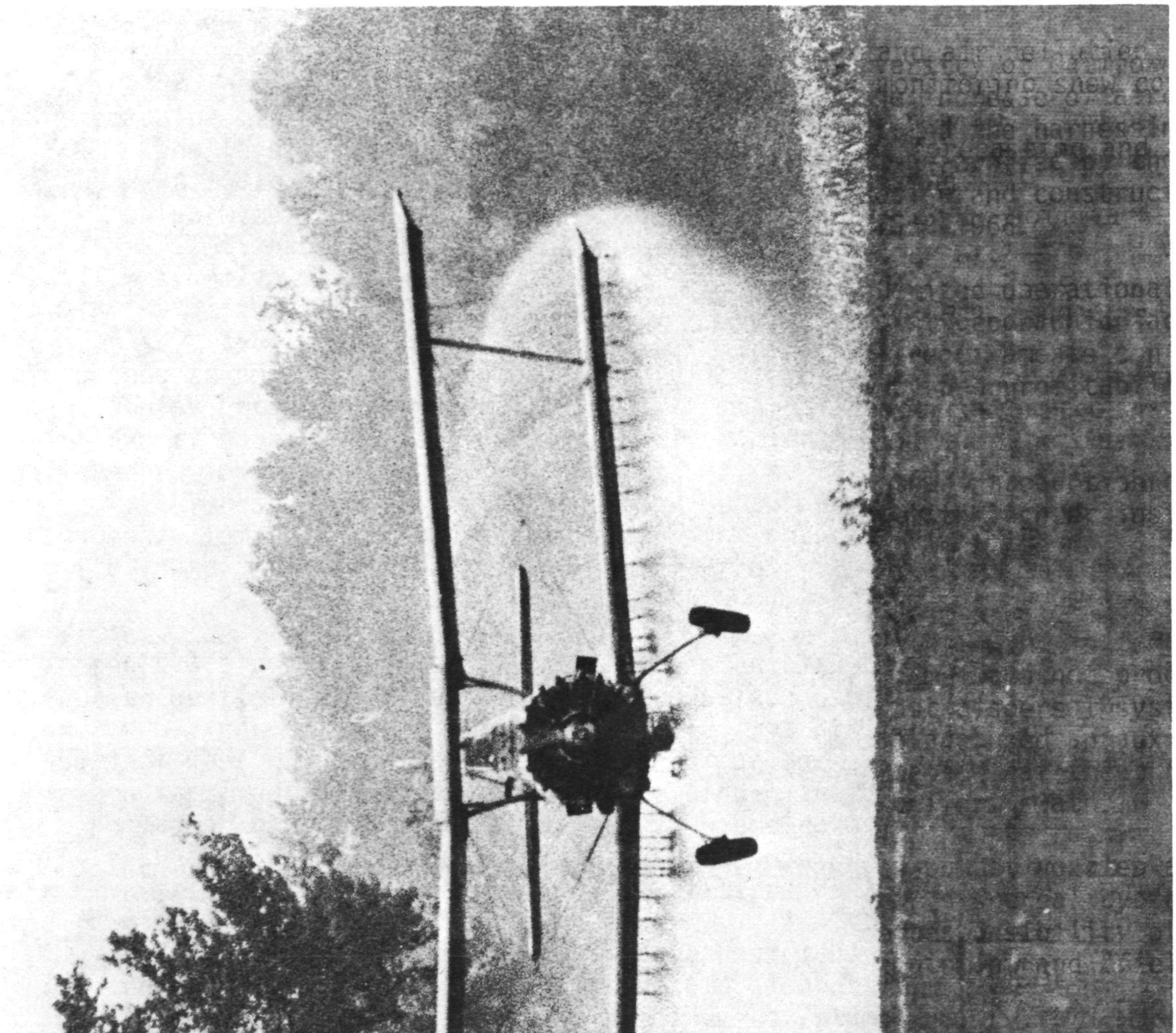

FIGURE 4-4 SPRAYING PEANUTS IN VIRGINIA
- Courtesy, Jim Livengood,
Daily Press

4.5 ECOLOGICAL CONSIDERATIONS

In the development of a new technology or in more extensive use of an existing technology, care must be taken to minimize danger to the ecosystem. The term "ecosystem" will be used to describe the system which includes the new technology and its environment. The term "ecosystem" was coined by the British plant ecologist, Tansley, in 1935, as a holistic unit comprised not only of vegetation, but also of the environment of that vegetation including climate, soils, and animals (ref. 8).

An energy balance of an ecosystem may be made which includes intake of energy into the system, energy flow through the food chain, total biomass of the system, and eventual consumption and loss of energy to the exterior. In this ecosystem the focus is on the total system rather than upon some one plant or animal species.

Ag-air operations utilize many chemicals for pesticides, herbicides, fungicides, nematicides, fertilizers, etc. These chemicals are comprised of basic ingredients which have been taken from the system, refined and/or synthesized in order to be used to increase crop production by eradicating pests, controlling weeds, or providing nutrients to the crops. Agriculture is dependent upon chemical formulations to assist the development of a more efficient system. Another approach might be development of biological agents to assist in production of food and fibers.

In the past, agriculture has used various practices which caused soil erosion, killed beneficial insects, and otherwise upset the ecosystem. Agriculturists have also been somewhat careless. Frequently they have been interested in harvesting the greatest volume of crops possible for the least cost with little thought about the ecosystem. The Extension Service has also been guilty of some shortsighted recommendations to the agricultural community. What they have done, however innocently, is to encourage and advise toward maximum, immediate, economic exploitation of the land without regard for long term results (ref. 9). Forestry has also suffered from the same attitude. Insecticides have been used to combat pests which take a tremendous toll of our forest resources; however, insecticides rarely eradicate the pests and frequently damage the ecosystem. Many foresters are ill-informed regarding other types of wildlife, such as birds, bees, etc., that are being damaged or changed. The gypsy moth is a severe nuisance to the forest. Reports indicate that in some cases the use of pesticides to control this pest do more damage to the ecosystem than the loss of timber from the infestation of the moth. This report does not advocate banning use of pesticides, but that they be used wisely and that alternative methods, such as biocontrol, be considered.

Some insects are beneficial. Other insects are considered pests. For example, the bee is a very useful insect, pollinating certain plants. The locust, which attacks various food and fiber crops, is considered a pest. In any situation to spray locusts during the daylight hours while they are feeding on a crop, such as alfalfa, would be very damaging to bees which are also on alfalfa when in bloom. It is unwise to assume that when chemical applications are made only "bad" insects are controlled or eradicated while "good" ones are not affected. Pesticides application will affect most insects and birds in the "target area".

Some of the materials which are applied miss the "target" areas, and some are transported from the area. Materials move in the ground water of the soil, some move due to surface runoff, some are transported in bodies of animals in the food chain, and some react with other materials to form undesirable chemical compounds (ref. 10 & 11). There is also the problem of movement through the air, as various chemicals may evaporate or sublime allowing their vapors to invade the target's surroundings. Many chemicals emit vapors, the amount being dependent upon moisture in the soil, humidity, wind, or temperature.

Other land parts of the ecosystem deserving mention in relation to pest and weed control include wildlife refuges, ranges and pastures, right-of-ways, and roadways. Wildlife probably suffers most immediately from careless or improper pesticide application on refuges and adjacent land. Scientific studies indicate that species are killed and chemicals move through the food chain affecting various phases of the reproductive cycle.

Rangeland management includes eradication and control of brush, weeds and other enemies of grass for grazing. The role of fires for conditioning grasslands during our country's early years has been replaced by brush and weed control through aerial herbicidal sprays. There has also been widespread bulldozing and/or other mechanical removal of unwanted plants in recent years. Many of these methods of eradication or control of vegetation unbalance the ecosystem.

Right-of-ways and roadsides, which occupy more of our country than all six New England states put together, are a problem. Herbicides are continually used to control vegetation growing on these areas. Investigation into the effects of these operations on the ecology of the area is needed.

By their general nature, application of agricultural technologies tends to promote ecological change. Technically-produced ecosystems tend to be unstable, but they are biologically successful. Productivity of correctly managed farm systems is generally far greater than systems that occur naturally. To achieve high production, man regulates the system and controls competition within the system.

The availability of effective chemicals has greatly contributed to the advancement of agriculture in the United States. Chemicals have been used to provide nutrients as well as to control insects, pests, weeds, etc. Agricultural chemicals have become an integral part of modern agricultural technology and pesticides have freed man from certain communicable diseases by eliminating the intermediate organisms or vector media. Such diseases as malaria, typhus and yellow fever, once greatly feared, have been either curtailed or eradicated from parts of the world.

In recent years there has been concern about various kinds of chemical residues that seem to be injurious to certain plants and animals, and there are continuing questions about the effect of these residual accumulations on human health. There is need for better understanding of the natural degradation of pesticides, of movement of pesticides in the environment, and of alternatives to chemical pesticides. There is also need for more research in terms of more accurate application on target areas and the use of chemicals which are more specific and hence less dangerous to non-target areas or species.

Marine Ecological Considerations

Because oceans and seas comprise the final earth system remaining for human exploitation, they deserve especially careful consideration. It was once thought that the ocean could absorb any amount of waste from man's terrestrial activities. It is now realized that this is not the case. The residence time (the time a given material spends in a given oceanic area) of a pollutant on a continental shelf is turning out to be much longer (some months) than previously thought. Another recent discovery is that decomposition rates of some manmade materials are much slower than previously thought. When the deep submersible "Alvin" flooded and fell to the bottom of the sea in October 1968, it was thought that the electronic equipment aboard would be unsalvageable. However, when it was recovered the following spring, it was found that practically no deterioration had taken place. These two effects taken together suggest that when an agricultural chemical finds its way into the sea, it may spend several months sloshing along the coast before moving into the open ocean, and it may take a very long time before decomposition takes place.

This persistence leads to another aspect of marine pollution: synergy, or the ability of materials to combine to form new substances possibly more harmful than the constituents. If an agricultural chemical is slow to be broken down, there is time available for such deleterious behavior.

If the ocean's threshold (the pollution level at which the ocean's regenerative powers are lost) is reached, then we will have destroyed our final hope for establishing a perpetual and beneficial ecological equilibrium with nature.

Aquaculture poses some very special problems in the maintenance of the environment. An aquaculture site has high potential for rapidly producing new strains of bacteria which could spread beyond the confines of the original site. Since the transport medium is flowing water, the possibility of rapid widespread biological damage is high. Such ecological upsets would be in addition to the predictable ones caused by poisons used against species competing with the desired crop, organic materials resulting from excess primary production, and the altered sedimentation and flow patterns due to the construction of the facilities themselves.

Historically, we have waited until a pollutant or industrial project manifested itself in some harmful form, studied the effects, then obtained legal sanctions against further use or construction. This process can take up to three decades. A well-known example is the tragic Minimata Bay (Japan) mercury poisoning (ref. 12). The EPA and other government agencies are trying now to improve the situation by anticipating and predicting effects of all new substances before they are released into the marine environment. This approach requires much theoretical and laboratory work, and is to be encouraged as preferable to the former "go ahead and use it and then we'll worry about it" approach. However, it is nearly impossible to predict all the synergistic products possible in the sea; some will likely be formed in the sea. This probability provides the rationale for extensive water quality monitoring by all the means available to geophysicists, earth scientists, and biologists.

Because of the impact pesticides have upon the environment, federal and state legislation have been enacted to regulate their use. The Environmental Protection Agency is the primary agency involved in national regulation of pesticides. The EPA's authority for action is derived from the Federal Insecticide, Fungicide and Rodenticide Act, which establishes the procedure for determining which pesticides may be used and under what conditions.

A primary criterion for judging application must be minimum long term damage to the ecosystem.

4.6 DEMOGRAPHIC CONSIDERATIONS

The preoccupation of most of mankind is to obtain enough food to survive. The old Malthusian concept that population will outgrow the food supply is still valid. It is a constant struggle for survival in most of the underdeveloped countries. The world population of over 4 billion is doubling every 35 years, and the per capita food supply has fallen slightly behind since 1972 (ref. 13). As the leading exporter of food, the United States has an agonizing decision to make. One possibility is to select certain countries that we think can achieve a stable population, and to help these countries alone. Thus we will have to decide which countries will receive our food aid and which will not; all the while realizing that (depending on our decision) a large number of people will die. The other possibility is to expand agricultural yields not only in the United States but in the world, attempt to feed the world, and hope that most countries can increase their standard of living. With an improvement in their economic situation, countries will often stabilize their populations. The increased harvest of 1977 is cited as a positive factor that will make stabilization possible. In addition, according to this program, there should be a concentrated effort in the developed countries to limit and then reduce food consumption. The reduced consumption should apply not only to food, but to energy, fossil fuels and nonrenewable minerals.

Further complicating the United States policy toward food is the hopeless attitude of some individuals that the population increase is too accelerated to stop now and that the world will face a period of not just insufficient food supply, but of famine and mass starvation in the underdeveloped countries.

Any food aid to countries with rapidly expanding populations is not only futile, but will actually make matters worse when the crunch comes. The people we keep alive now will breed and increase the population and the severity of the coming famine.

Thus, at the present time there is great international anxiety about what to do about the growing population. One thing is clear, the present growth of the population cannot continue, and if man is unable to stabilize the world population, the forces of nature will do it. At the present time per capita food supply could decline disasterously with unfavorable weather or a decline in the energy supply. Relatively small changes in supply can create havoc in price structure and nutritional standards. Even at the present time the underdeveloped countries have built up a population dependent not only on the weather, but also upon economic conditions and political whims in the developed countries. Developed countries in turn are dependent for their energy for agriculture on economic and political situations in the OPEC countries. Food availability is dependent on a tenuous and fortuitous chain of circumstances. A storage system to maintain stocks against shortages is a partial solution to short run problems.

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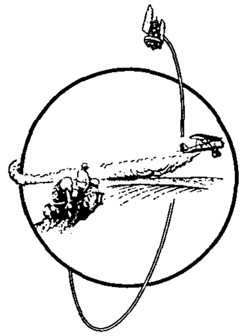
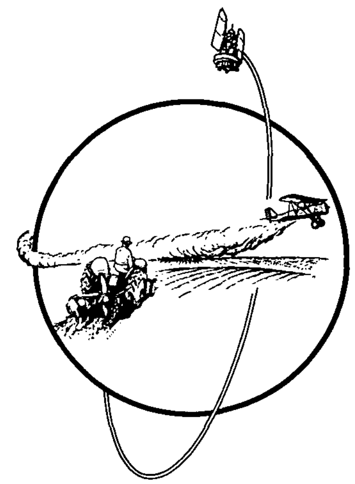


PART II

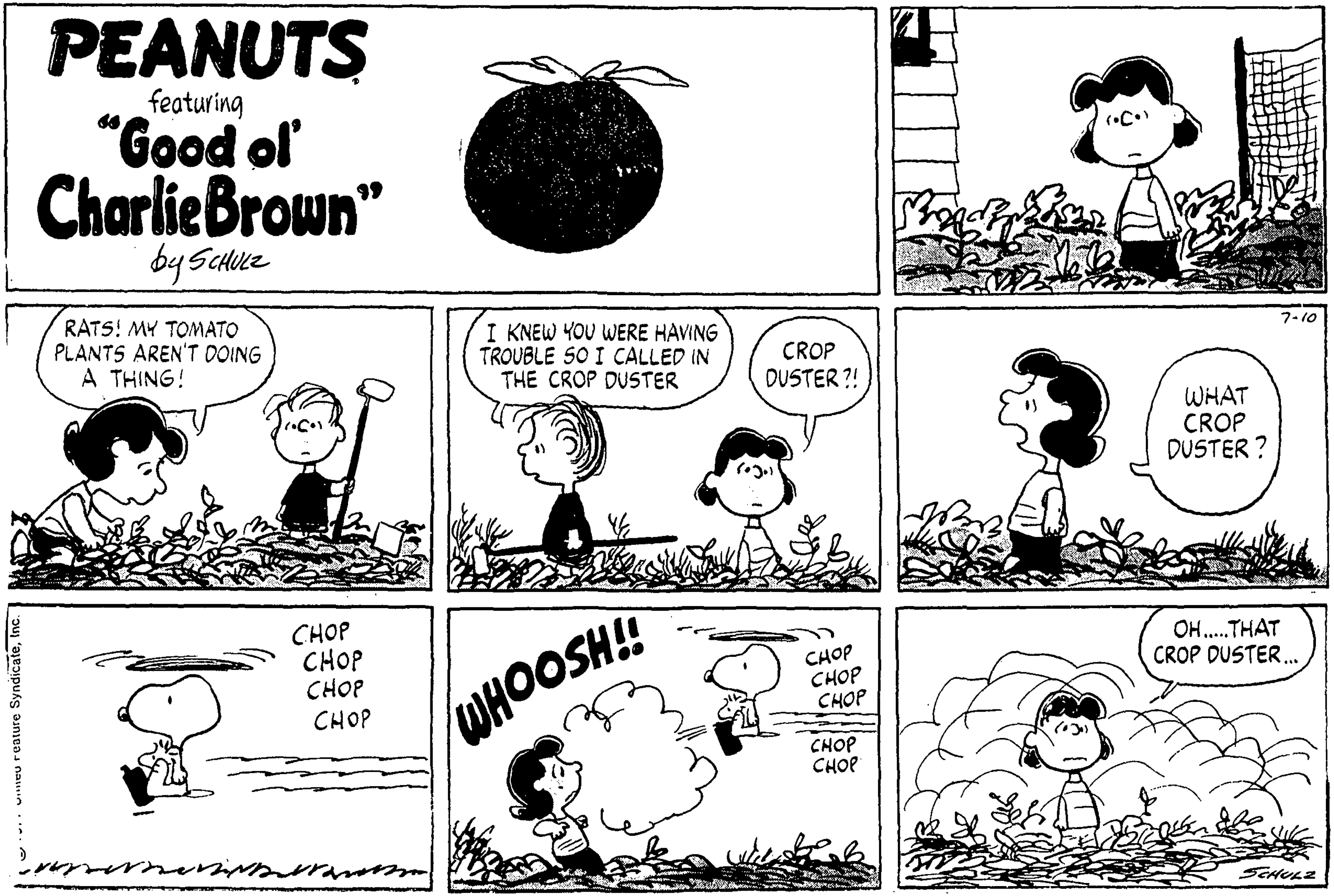
Examination and Evaluation of Subsystems:

The Frame work Within Which Agriculture and Aerospace Operate and Possible Means of Obtaining Objectives.

5



Agricultural Aviation


PEANUTS
featuring
"Good ol' Charlie Brown"
by SCHULZ
RATS! MY TOMATO PLANTS AREN'T DOING A THING!
I KNEW YOU WERE HAVING TROUBLE SO I CALLED IN THE CROP DUSTER
CROP DUSTER?!
7-10
WHAT CROP DUSTER?
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CHOP
CHOP
CHOP
CHOP
WHOOSH!!
CHOP
CHOP
CHOP
CHOP
CHOP
OH.....THAT CROP DUSTER...
SCHULZ

CHAPTER 5

AGRICULTURAL AVIATION

5.1 INTRODUCTION

The farmer intervenes in the life cycle of the domesticated plant and animal to improve its chances for a healthy vigorous life leading to a high yield of food and other products at harvest time. He does this by properly selecting and preparing the soil and farm structures; by careful planting and stocking; by irrigating and watering; by fertilizing and feeding; by controlling weeds, insects, and other pests; by protecting against fire and storm; and by efficient harvesting. It is the intent of this chapter to examine the role of aerospace technology in aiding the farmer in these acts. In particular, we shall examine the role of agricultural aircraft, which is commonly referred to as ag-air.

There are so many possible uses of aircraft in farming that we have not had time to examine all of them in depth. We shall concentrate on matters pertaining to the aerial application of pesticides, fertilizers, and seeds primarily on cultivated fields. Little attention will be given to aircraft use in forestry, cloud seeding, and a number of other agriculture-related activities. The plan of the chapter will be to first look at the subject of pesticides because these present some of the more interesting and more difficult problems in aerial applications. Among pesticides we shall include herbicides, insecticides, and fungicides which form the bulk of pesticides used in aerial applications. Next we look at seeding, stocking and fertilizing which are primarily dry applications and, therefore, differ in important ways from pesticides that are usually dispensed in solutions or liquid suspensions. The final parts of the chapter deal with the aircraft, dispersal, and guidance systems.

5.2 PEST CONTROL

The control of both animal and plant pests is an integral part of modern agricultural technology. Despite the best efforts of the agri-industry, a recent report (ref. 1, p. 1) tells of an estimated 34 percent preharvest crop loss to pests in the United States. The report goes on to state that in developing nations in the tropics, the preharvest loss to pests is an estimated 50 percent. The percentage may be much higher in some places. Effective pest control remains, therefore, a goal rather than a reality.

Pesticide Application

The discussion that follows is limited to the agricultural applications of pesticides. In so doing, the report ignores the important uses of these chemicals in forestry and public health (e.g., mosquito abatement). In a report of this nature the discussion, of necessity, must be general although some specific crops are used to illustrate the relative volumes of various pesticides that are applied. These crops are cotton, corn, wheat, rice and soybeans and account for a significant portion of world production in food and fiber. They also account for much of the pesticide currently used in the United States (ref. 2, p. 14). The term pesticides includes both herbicides and pesticides. Herbicides are the fastest growing pesticide. Exactly how much growth has occurred is difficult to determine; the most recent USDA figures for all pesticides are from 1971. Table 5-1 accounts for the 1971 herbicide uses on the five major crops.

TABLE 5-1

FARM USES OF HERBICIDES ON FIVE MAJOR CROPS IN PERCENT

Corn	45%
Soybeans	16
Cotton	9
Wheat	5
Rice	3
All Others	22
Total	100%

(ref. 2, p. 11)

The potential benefits of increased herbicide use are great. This is particularly true in countries like India where crop loss to weeds ranges between 30 and 100 percent annually. In contrast, annual United States loss to weeds ranges between 8 and 24 percent (ref. 3, p. 45).

Potential problems from herbicides are few. Generally speaking, herbicides pose little danger to mammals and are quickly broken down in the soil (ref. 4, p. 205). Perhaps the greatest damage from herbicides is the damage that can occur to neighboring non-target crops; therefore, solving the problem of herbicide drift would largely solve the problems associated with herbicides.

Insecticides

The major problem associated with insecticides is that of pollution. Chlorinated hydrocarbons such as DDT do not break down quickly in the soil. The chemical remains on soil particles, which may be transported by runoff into bodies of water where the DDT accumulates in bottom sediments and enters the marine food chain. Higher concentrations of the compound are found in animal tissue at each subsequent trophic level (ref. 5, p. 5). This process, known as biomagnification, also occurs in land animals. For example, unacceptable concentration of DDT has occurred in the milk from cows which forage on crops which have come into contact with DDT (ref. 6). DDT was once the most widely used insecticide; its use has since been restricted in the United States. Widely used today are the biodegradeable organophosphates and carbamate insecticides. But these still pose danger to non-target species in the area of application. Frequently, a pest predator will be killed in greater numbers than the pest, Damage may also occur to beneficial species such as earthworms (ref. 8, pp 131-132).

A rather complete summary of pesticide use in agriculture is given in Tables 5-3 through 5-7 (ref. 10).

Aerial Application

Approximately 27 percent of all pesticide treatments, in the United States, are done by air (ref. 10, p. 3). In some areas (e.g., California as much as 50 percent of the total is applied by air. Table 5-2 indicates the proportion of farmers who use pesticides who also utilize aerial application (custom application).

TABLE 5-2

PERCENTAGE OF FARMERS RAISING A SPECIFIC CROP WHO USE PESTICIDES AND THE PERCENTAGE WHO USE CUSTOM APPLICATION

Crop	Percentage of Farmers Using Pesticides	Percentage of Pesticide Users who Purchase Custom Application
Corn	68	33
Soybeans	63	22
Cotton	86	51
Wheat	23	47
Rice	91	100

(ref. 10, p. 8)

The contents of Table 5-2 are based upon 1971 data. Aerial applications can be expected to have grown enormously since that time for several main reasons including: the higher costs of purchasing, operating and maintaining ground application equipment; increased restriction on who may obtain a license to apply pesticides; and the timeliness of application even when field conditions or crop growth stage prohibit the use of ground equipment. Table 5-8 compares costs of ground and air applications for our five crops.

TABLE 5-3

Table 10.--Expenditures per acre for custom pesticide services ...

EXPENDITURES PER ACRE FOR CUSTOM PESTICIDE SERVICES (APPLICATION AND MATERIALS), 1971 1/

Crop category	Applied with ground equipment					Applied with aircraft					
						Fixed wing				Helicopter	
	Dust	Spray	Granular	Mixed with fertilizer	Other 2/	Dust	Spray	Granular	Other 2/	Dust	Spray
	Dollars										
Corn	3.71	4.78	4.37	5.22	4.79	4.08	4.23	3.57	.64	4.75	3.33
Cotton	18.14	5.23	7.55	5.39	12.75	8.79	6.50	18.18	3.20	--	8.85
Wheat	--	1.68	2.46	1.75	--	3.19	1.91	4.47	--	--	1.20
Sorghum	5.24	3.69	3.93	6.01	--	5.30	2.58	4.08	--	--	2.46
Rice	--	6.50	--	--	1.91	--	6.47	10.58	4.42	--	3.65
Other grains 3/	--	1.88	2.17	1.53	1.30	3.65	1.88	4.54	--	--	1.31
Soybeans	19.60	5.81	6.06	9.96	3.12	5.36	3.27	12.65	1.12	--	2.68
Tobacco	8.91	10.68	--	20.00	--	11.12	16.54	--	--	--	--
Peanuts	6.85	6.29	6.15	--	--	8.22	13.49	6.76	--	--	20.66
Sugarbeets	3.68	9.99	9.05	--	21.94	13.73	6.77	3.96	7.28	--	4.49
Other field crops 3/	5.40	6.06	3.65	2.69	--	4.27	5.17	5.76	--	--	4.37
Alfalfa	2.80	4.14	3.92	--	5.26	--	4.44	4.90	--	--	5.65
Other hay and forage 3/	--	2.98	--	--	--	--	1.83	--	--	--	--
Pasture	--	2.23	--	.18	--	--	2.87	.20	--	--	3.40
Potatoes	--	11.20	18.51	17.07	29.55	5.17	34.41	--	--	--	7.86
Other vegetables 3/	11.97	8.40	3.58	9.55	21.88	6.55	8.03	9.78	--	19.23	9.45
Citrus	8.30	9.86	10.27	--	5.74	--	11.19	--	--	--	9.92
Apples	--	8.37	--	--	--	--	4.75	--	--	--	8.99
Other deciduous fruit 3/	3.65	9.52	--	--	--	47.48	12.29	--	--	19.83	12.61
Other fruits and nuts 3/	8.92	9.64	6.98	7.53	68.59	17.21	9.41	9.47	--	6.15	6.31
Nursery and greenhouse	--	--	--	--	--	--	--	--	--	--	--
Summer fallow	--	2.95	--	--	--	--	4.67	--	--	--	--
All crops	10.35	4.76	5.79	5.62	10.11	8.81	3.81	4.64	4.27	8.47	4.84

-- = None reported.

1/ Alaska excluded.

2/ Includes foams, strips, baits, rubs, and so forth.

3/ Crops included in this category are listed in the appendix.

TABLE 5-4

EXPENDITURES PER ACRE FOR CUSTOM PESTICIDE APPLICATION (NOT INCLUDING MATERIALS), 1971 1/

Crop category	Applied with ground equipment					Applied with aircraft					
						Fixed wing				Helicopter	
	Dust	Spray	Granular	Mixed with fertilizer	Other 2/	Dust	Spray	Granular	Other 2/	Dust	Spray
	--- Dollars ---										
Corn	.94	1.17	1.11	.74	1.59	1.53	1.56	1.34	.18	2.11	1.82
Cotton	2.46	1.81	5.47	.47	3.25	3.23	2.72	8.38	.70	--	3.47
Wheat	--	.80	1.00	1.19	--	1.18	1.06	1.90	--	--	.72
Sorghum	2.23	1.17	1.25	.86	--	1.95	1.32	1.41	--	--	1.54
Rice	--	1.94	--	--	.91	--	1.75	1.04	2.50	--	3.01
Other grains 3/	--	.98	1.01	.95	--	1.32	1.10	1.92	--	--	.83
Soybeans	4.00	1.19	1.40	1.13	1.25	1.45	1.25	5.90	.16	--	1.39
Tobacco	4.14	3.39	--	10.00	--	3.89	9.22	--	--	--	--
Peanuts	1.92	1.15	1.11	--	--	2.36	3.85	1.24	--	--	3.26
Sugarbeets	1.05	2.09	2.16	--	4.11	6.34	3.67	2.56	1.65	--	3.23
Other field crops 3/	2.00	1.69	1.21	1.49	--	1.46	2.06	1.78	--	--	1.45
Alfalfa	2.00	1.46	1.12	--	1.55	--	1.85	2.00	--	--	2.13
Other hay and forage 3/	--	1.07	--	--	--	--	1.02	--	--	--	--
Pasture	--	1.14	--	--	--	--	1.18	.05	--	--	2.56
Irish potatoes	--	3.22	3.11	6.57	4.74	2.04	3.37	--	--	--	2.78
Other vegetables 3/	2.13	2.49	1.26	3.82	2.68	2.43	2.37	2.82	--	4.36	4.11
Citrus	3.42	4.93	2.70	--	2.87	--	4.35	--	--	--	3.54
Apples	--	2.78	--	--	--	--	1.92	--	--	--	5.15
Other deciduous fruit 3/	1.00	2.87	--	--	--	5.64	6.31	--	--	8.91	7.61
Other fruits and nuts 3/	4.79	3.09	2.05	1.98	16.71	5.17	3.92	4.00	--	3.32	3.58
Nursery and greenhouse	--	--	--	--	--	--	--	--	--	--	--
Summer fallow	--	.78	--	--	--	--	1.59	--	--	--	--
All crops	2.56	1.43	1.74	.91	2.04	2.57	1.75	1.53	1.01	2.99	2.20

-- = None reported.
1/ Excludes Alaska.
2/ Includes foams, strips, baits, rubs, and so forth.
3/ Crops included in this category are listed in the appendix.

TABLE 5-5

EXPENDITURES PER ACRE FOR CUSTOM-APPLIED PESTICIDE MATERIALS (NOT INCLUDING APPLICATION COST), 1971 1/

Crop category	Applied with ground equipment					Applied with aircraft					
						Fixed wing				Helicopter	
	Dust	Spray	Granular	Mixed with fertilizer	Other 2/	Dust	Spray	Granular	Other 2/	Dust	Spray
	--- Dollars ---										
Corn	2.77	3.61	3.26	4.48	3.20	2.55	2.67	2.23	.46	2.64	1.51
Cotton	15.68	3.42	2.08	4.92	9.50	5.56	3.78	9.80	2.50	--	5.38
Wheat	--	.88	1.46	.56	--	2.01	.85	2.57	--	--	.48
Sorghum	3.10	2.52	2.68	5.15	--	3.35	1.26	2.67	--	--	.92
Rice	--	4.56	--	--	1.00	--	4.72	9.54	1.92	--	.64
Other grains 3/	--	.90	1.16	.58	1.30	2.33	.78	2.62	--	--	.48
Soybeans	15.60	4.62	4.66	8.83	1.87	3.91	2.02	6.75	.96	--	1.29
Tobacco	4.77	7.29	--	10.00	--	7.23	--	--	--	--	--
Peanuts	4.93	5.14	5.04	--	--	5.86	9.64	5.52	--	--	17.40
Sugarbeets	2.63	7.90	6.89	--	17.83	7.39	3.10	1.40	5.63	--	1.26
Other field crops 3/	3.40	4.37	2.44	1.20	--	2.81	3.11	3.98	--	--	2.92
Alfalfa	.80	2.78	2.80	--	3.71	--	2.59	2.90	--	--	3.52
Other hay and forage 3/	--	1.91	--	--	--	--	.81	--	--	--	--
Pasture	--	1.09	--	.18	--	--	1.69	.15	--	--	.84
Irish potatoes	--	7.98	15.40	10.50	14.81	3.13	3.18	--	--	--	5.08
Other vegetables 3/	9.84	5.91	2.32	5.72	19.20	4.12	5.66	6.96	--	14.87	5.34
Citrus	4.88	4.93	7.57	--	2.87	--	6.84	--	--	--	6.38
Apples	--	5.59	--	--	--	--	2.83	--	--	--	3.84
Other deciduous fruit 3/	2.65	6.65	--	--	--	41.84	5.98	--	--	10.92	5.00
Other fruits and nuts 3/	4.13	6.55	4.93	5.55	51.88	12.04	5.49	5.47	--	2.83	2.73
Nursery and greenhouse	--	--	--	--	--	--	--	--	--	--	--
Summer fallow	--	2.17	--	--	--	--	3.08	--	--	--	--
All crops	7.79	3.33	4.05	4.71	8.07	5.61	2.06	3.11	3.25	5.47	2.64

-- = None reported.
1/ Excludes Alaska.
2/ Includes foams, strips, baits, rubs, and so forth.
3/ Crops included in this category are listed in the appendix.

TABLE 5-6

PERCENTAGE DISTRIBUTION OF EXPENDITURES FOR CUSTOM-APPLIED PESTICIDE MATERIALS 1/

Year	Form of pesticide				
	Dust	Spray	Granular	Mixed with fertilizer	Other 2/
	Percent				
1964	10	88	1	3/	1
1966	8	87	4	1	3/
1971	3	88	5	2	1

1/ Excludes Alaska and Hawaii in 1964 and 1966 and excludes Alaska in 1971.
2/ Includes foams, baits, strips, aerosols, rubs, and so forth.
3/ Less than 0.5 percent.

PERCENTAGE DISTRIBUTION FOR 1971 1/

Crop category	Form of pesticide				
	Dust	Spray	Granular	Mixed with fertilizer	Other 2/
	Percent				
Corn	2	87	6	5	3/
Cotton	4	82	2	3/	1
Wheat	1	95	4	3/	--
Sorghum	1	84	14	2	--
Rice	--	90	10	--	3/
Other grain 4/	3/	95	5	3/	1
Soybeans	2	84	11	3	3/
Tobacco	2	98	--	--	--
Peanuts	15	84	1	--	--
Sugarbeets	8	64	7	9	12
Other field crops 4/	1	97	2	3/	--
Alfalfa	3/	97	2	--	1
Other hay and forage 4/	--	100	--	--	--
Pasture	--	99	3/	--	--
Irish potatoes	1	95	4	3/	3/
Other vegetables 4/	9	82	1	2	6
Citrus	4	94	2	--	3/
Apples	--	100	--	--	--
Other deciduous fruit 4/	34	66	--	--	--
Other fruits and nuts 4/	10	87	1	1	1
Nursery and greenhouse	32	68	--	--	--
Summer fallow	--	100	--	--	--
All crops	3	89	5	2	1

-- = None reported.
1/ Excludes Alaska.
2/ Includes foams, baits, strips, rubs, and so forth.
3/ Less than 0.5 percent.
4/ Crops included in this category are listed in the appendix.

TABLE 5-7

PERCENTAGE DISTRIBUTION OF FARMS USING CUSTOM PESTICIDE SERVICES AND OF APPLICATION CHARGES, 1971 1/

Crop category	Type of equipment					
	Ground (surface)		Fixed wing aircraft		Helicopter	
	Farms reporting 2/	Custom expenditures 3/	Farms reporting 2/	Custom expenditures 3/	Farms reporting 2/	Custom expenditures 3/
	Percent					
Corn	88	64	12	34	3	2
Cotton	34	12	72	87	1	1
Wheat	40	27	60	72	1	1
Sorghum	43	19	60	80	4/	1
Rice	10	1	96	99	1	4/
Other grain 5/	56	40	43	59	2	1
Soybeans	72	46	27	51	2	3
Tobacco	98	74	5	26	--	--
Peanuts	46	24	62	75	1	1
Sugarbeets	61	36	40	62	10	2
Other field crops 5/	40	19	70	80	3	1
Alfalfa	64	21	32	74	6	5
Other hay and forage 5/	87	60	18	40	--	--
Pasture	42	16	56	75	2	9
Irish potatoes	42	19	83	77	2	4
Other vegetables	56	44	54	44	11	12
Citrus	99	94	5	2	3	4
Apples	50	20	39	71	11	9
Other deciduous fruit 5/	72	57	24	32	20	11
Other fruit and nuts 5/	69	63	30	35	3	2
Nursery and greenhouse	44	57	30	37	36	6
Summer fallow	67	49	36	51	--	--
All crops	70	35	34	63	3	2

-- = None reported.

1/ Excludes Alaska.

2/ Survey farms reporting custom pesticide services employing this type of application equipment as percentage of survey farms reporting custom pesticide services for all types of application equipment. May add to over 100 percent due to use of more than one type of custom equipment by individual farmers.

3/ Expenditures for custom application charges employing this type of application equipment as percentage of expenditures for custom application charges for all types of application equipment.

4/ Less than 0.5 percent.

5/ Crops included in this category are listed in the appendix.

TABLE 5-8

COST PER ACRE OF SPRAY MATERIALS AND APPLICATION COST BY GROUND AND FIXED-WING AIRCRAFT AND THE PERCENTAGE DIFFERENCE IN PRICE

Crop	Ground Application	Air Application	Percentage Difference Air to Ground
Corn	$4.78	$4.23	-11%
Soybeans	5.81	3.27	-44%
Cotton	4.23	6.50	+24%
Wheat	1.68	1.91	+14%
Rice	6.50	6.47	-.5%

Aerial application is clearly cost competitive in all five crops. In the case of soybeans and corn, aerial application is considerably cheaper. When the factor of timeliness is added aerial application becomes even more attractive.

But air application of pesticides is not without problems. Much of the pesticide drift, about which the environmentalists are concerned, is caused by aerial application. This drift can damage neighboring non-target crops and non-target species of insects and mammals. In addition a systematic approach to increasing agricultural crop production starts with an understanding of the needs of the crop and its environment. This general statement holds true for specific tasks such as aerial chemical application. The Research Council of Canada (ref. 12) has summarized this very well in the following statements: "...All agricultural and forestry aviation must be based on biological needs..." and "...The biology is the basic concern: the application technique and equipment is subordinate to the biological requirement..." This section provides a brief survey of plant pests and emphasizes the enormous problem of variability facing the chemical formulator and the pesticide applicator.

A. Insects

Insects are probably the most variable and dynamic of all pests. All species have basically four stages in their life cycle - egg, larva, pupa, adult. Some species infesting a field may have three or four generations within a single growing season. Generally the larva stage is the most damaging to the host plant. Within the life cycle of a particular species the larva may feed in the stalk or roots and the adult may concentrate on the leaves. The pink bollworm larva, for example, feeds on cotton squares the first few days, then moves down the plant to the boll.

TABLE 5-9

FEEDING HABITAT OF INSECTS OF SOME COMMON CROPS

Crop	Insect	Feeding Habitat
Corn	European Corn Borer	Early stages - leaves & whorl Later stages - embed in stalk
	Corn Earworm	Early stages - whorl Later stages - ears & maturing grain
	Southwestern Corn Borer	Early stages - bore in stalk above ground Later stages - tunnel down stalk below ground
	Corn Rootworm Beetle	Adult feeds on corn silk, larva on roots
	Common Stalk Borer	Larva tunnels in stalk
Soybeans	Mexican Bean Beetle	Chew holes from underside of leaves, pods
	Bean Leaf Beetle	Larvae chew roots, nodules & subsurface stems Adults - stems of seedlings, leaves and pods
	White Grubs	Feed on Roots
Small Grains	Cereal Leaf Beetle	Feeds on leaves
	Greenbug	Sucks sap from leaves
	Hessian Fly	Larvae - lower leaf sheaths
	Army Worms	Strip leaves, grains
Cotton	Pink Bollworm	Eggs on fruiting forms of plant, larvae in boll and squares.
	Boll Weevil	On cotton boll and squares

Table 5-9 illustrates the feeding habitats of some of the more common insects on agricultural crops and forests. This table clearly shows the magnitude of variability of insects from crop to crop, of various insect species on the same crop, and even the variability of the same species depending on the generation in the season or whether it is in the larval or adult stage.

B. Weeds

Although weeds, once germinated, are not mobile as are insects, they do still present a wide variation of life cycles, season of growth, physiology and methods of reproduction to the chemical formulator and the applicator. There are three principal groups - annuals, biennials, and perennials.

As an example of the diversity of weeds one finds in typical crops, Table 5-10 lists the number of different weeds by classification found in major crops in Kansas (ref. 13).

The chemical formulator must deal with major differences in plant chemistry and physiology within a given classification. He sees an additional variation of season of growth between classifications within the same crop. Additional challenges emerge for chemical selectivity when considering the plant biology of different crops. The problem is further complicated when considering the variations in soil types and climate across the country.

Although much knowledge about plant metabolic processes does exist, it is often spotty and disjointed. Present day knowledge is still inadequate to explain many of the step-by-step biological reactions plants have to chemicals.

TABLE 5-10

MAJOR WEEDS IN KANSAS AGRICULTURAL LAND

Crop	Weed Classification	Number
Corn, Sorghum & Soybeans	Summer annual broadleaf	12
	Summer annual grasses	10
	Perennials	8
Fall Seeded Small Grains	Winter annual broadleaf	6
	Winter annual grasses	4
	Summer annual broadleaf	7
	Perennials	3
Legume Hay Crops	Winter annual broadleaf	7
	Winter annual grasses	3
	Summer annual grasses	3
	Perennials	4

C. Plant Diseases

Although common plant diseases are largely controlled by planting disease-resistant crop varieties, pathogenic fungi, bacteria and viruses are of considerable concern to the producers of such high-value crops as potatoes, bananas, apples, most citrus fruits, vegetables, tobacco, and peanuts.

As with insects and weeds, there is a large variety of plant pathogens, and their interrelationship with the host crop and the microenvironment is not yet fully understood. An example of how insects and weeds can play a role in spreading disease is illustrated in Figure 5-1. Clearly a biological cycle such as this must be fully understood in order to provide effective control through chemical application.

5.3 AGRICULTURAL CHEMICALS AND BIOLOGICAL CONTROL

To better understand the biological aspects of chemical pesticide application, it is desirable to survey some of the more commonly used chemicals on the market today, and how they select the target to be controlled out of the crop and its microenvironment. Again this underlines the wide diversity of formulations and selectivity mechanisms used by the chemist and methods of application utilized by the applicator.

A. Insecticides

1. The Chemicals. The chlorinated hydrocarbons, (DDT, Dieldrin, Endrin, Heptachlor) used extensively for insect control years ago, exhibited a residual effect on their environment long after they were applied. Because of these environmental concerns and because of some build-up of insect resistance to these chemicals, the more volatile organophosphates (parathion, malathion, diazinon) have come into more common use. These rapidly release their toxicity for pest control and are subsequently biodegraded by sunlight, soil microorganisms, or other agents. Carbamates such as carbaryl (sevin) have also been recently developed as potent, narrow-spectrum insecticides and have shown to be plant systemic.

2. Mode of Action. The majority of insecticides kill by virtue of their effects on the nervous system. It is generally accepted that the chemical inhibits cholinesterase enzyme activity which in turn disrupts the nervous system. Insecticides adhering to the insect must possess special surface tension properties in order to penetrate the water repellent surface layer.

3. Selectivity. There are several factors which determine how an insecticide chemical "selects" the target pest from its environment but has little or no effect on other components of that environment. These factors are:

a. use of differences in behavior and habitat between target pest and other insects (i.e., where and when they feed, where they lay eggs, overwinter).

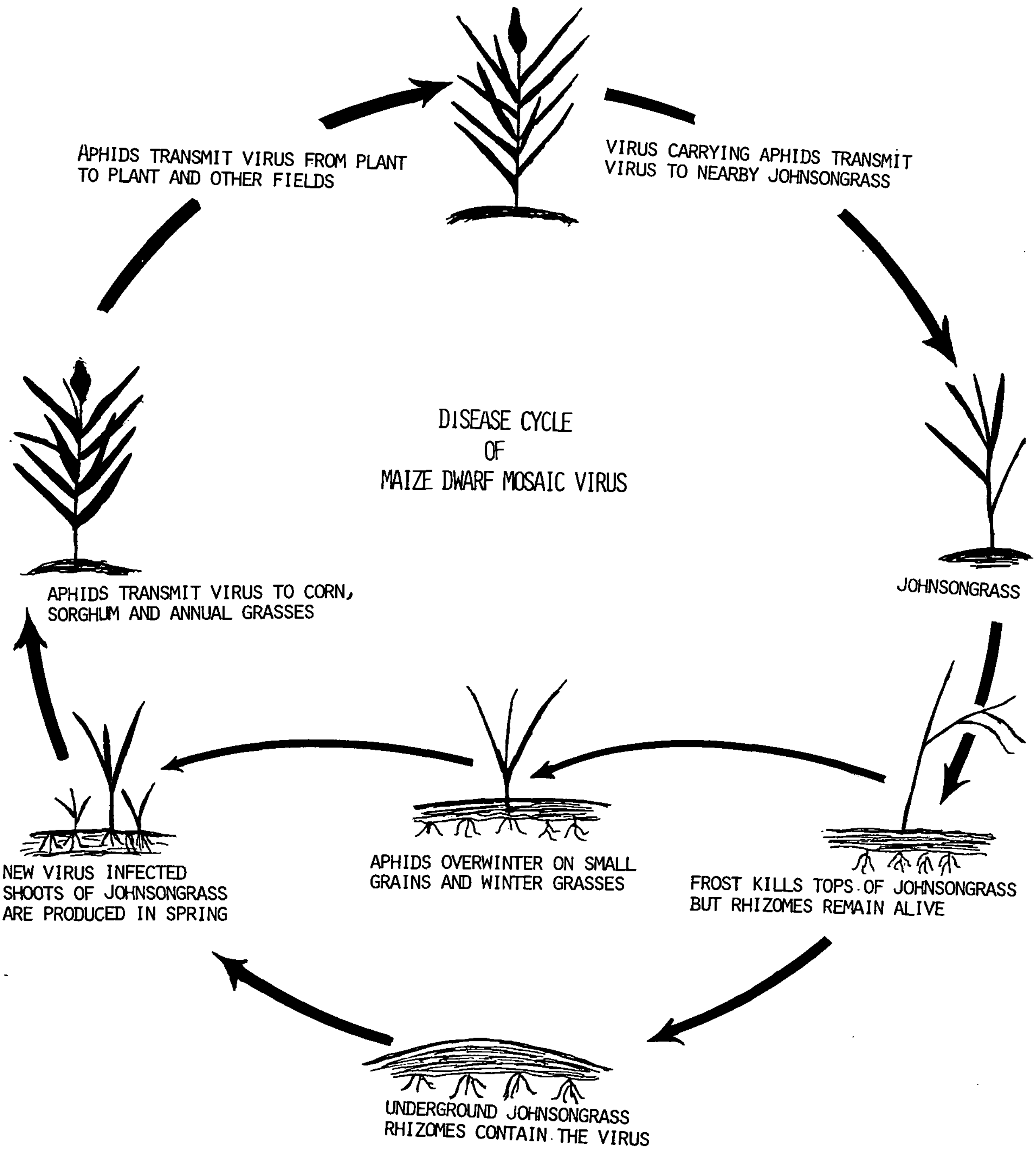


FIGURE 5-1 DISEASE CYCLE OF MAIZE DWARF MOSAIC.

b. use of differences in how the chemical penetrates the insect. Insects can either come in physical contact with a drop of chemical lying on a leaf, or they can ingest it by chewing or sucking on chemically treated plant tissue, or they can inhale it as a gas fumigant.

c. use of differences in rate of breakdown of chemical compounds in the metabolism of different species.

d. use of differences in how the chemical compound reaches and affects the insect's nervous system.

Thus far, no insecticide has been found with enough selectivity to discriminate between pest and beneficial species to any useful degree. Ecological selectivity (use of differences in behavior, location of feeding, etc) will probably remain as the primary selection mode for many years to come.

4. Chemical Formulations and Applications. Selection of a pesticide and its formulation depends on:

a. pest species
b. availability of pesticide
c. type of equipment available
d. hazards to off-target areas
e. cost
f. time of application

If soil insects are to be controlled or if the chemical is a preemergence application, the formulation will likely be granular. If an insect feeding on foliage is to be controlled, a liquid spray is normally used. If flying insects such as mosquitoes are to be controlled by contact spray, undiluted but highly atomized spray is used at ultra low volume rates.

Many times a chemical developed for a specific pest is insoluble in water. In this case a surfactant is added as an emulsifying agent, or the chemical may be formulated as a wettable powder to be applied as a suspension in water. Agricultural research stations and university extension services for each state test and recommend chemical formulations and application dosages and procedures for crops and pests in their state. An example of the diversity of a state's pesticide guide is shown in Table 5-11 excerpted from reference 14.

Systemic insecticides can control insects feeding on plant parts which regular applications cannot reach. Systemics are selective: they control sucking insects but not their predators. They are also persistent, remaining effective within the plant over a longer time than if they were on the surface.

B. Herbicides

1. The Chemicals. Herbicides can be classified in several ways. They can be grouped according to whether they are selective or non-selective. Selective herbicides can be grouped according to condition of application: pre-planting,

TABLE 5-11

1977 INSECTICIDE RECOMMENDATIONS FOR VIRGINIA

Crop	Insects	Insecticide	Formulation (See Footnote)	Application
Corn	Rootworm	Carbofuran	Liquid	7" band over row
		Dasanit	G	7" band over row
		Disulfoton	G	Band on side
		Dyfonate	G	Band incorporate
		Terbufos	G	7" band over row
		Phorate	G	Pre-plant
		Diazinon	G	Post-emergence
	Army Worm	Sevin	WP	Broadcast
	Japanese Beetle	Sevin	WP	Treat field
	Wireworm	Diazinon	G	Broadcast pre-plant
	1st Generation Eur Corn Borer	Carbofuran	G	7" band over row
	Eur Corn Borer	Carbofuran	G	Broadcast over foliage
		Diazinon	G	Broadcast over whorl
Small Grains	Army Worm	Parathion	EC	Spray foliage
		Malathion	EC	Spray foliage
	Aphids	Disulfoton	LC	Spray foliage
	Cereal Leaf Beetle	Guthion	EC	Spray foliage
Soybeans	Corn Earworm or	Sevin	WP	Spray foliage
	Fall Army Worm	Parathion	EC	Spray foliage
	Soybean Looper	Lannate	SP	Spray foliage
	Mexican Bean Beetle	Sevin	WP	Spray foliage
		Malathion	EC	Spray foliage
		Guthion	EC	Spray foliage

Note: G - Granular
WP - Wettable Powder
EC - Emulsifiable Concentrate
SP - Sprayable Powder

(From ref. 14)

preemergence, post-emergence, etc. These are also grouped according to foliage vs. soil application. Foliage-applied herbicides further divide into two large subgroups depending upon whether they kill by contact or by systemic action.

2. Mode of Action. Contact herbicides usually produce acute toxicity, rapidly killing the plant. Growth regulators or systemics produce chronic toxicity, slowly killing the plant. A considerable number of herbicides affect plants by blocking enzymic processes. Many theories have been advanced to explain the actual metabolic disruption by herbicides, and for this reason Crafts (ref. 15) states that there can be no general theory of herbicidal action since many mechanisms are involved in the killing of the plant.

3. Plant Absorption and Translocation

a. Absorption. Foliage-applied herbicides are absorbed by the plant predominantly through the leaves. The leaf typically has a natural water-repellent covering over it called the cuticle. Chemical absorption through this cuticle depends on the thickness of the cuticle and the "wetting and adhesive" quality of the chemical. Surfactants are added to the water-based chemical sprays to alter the surface tension and to enhance absorption through the cuticle.

There are openings in the cuticle called stomata which allow CO_2 to readily diffuse into the leaf for photosynthesis. A chemical drop coming in contact with these stomata is much more readily absorbed than through the more impervious cuticle layer. With most plant species, there is a greater concentration of stomata on the underside of the leaf than on the topside.

b. Translocation. Plants are made up of a continuous interconnected living protoplasm and a continuous interconnected non-living cellwall. Translocation of chemical through the plant may be via either the protoplasm or the cell wall, and proves to be a very complex mechanism. There is evidence, according to Crafts, that transport is from regions of synthesis of foods to regions of their utilization. This may explain why the chemical:

(1) moves from early leaves of seedlings to the roots.

(2) moves from later leaves to roots and shoot tips.

(3) moves from upper leaves to growing shoots.

4. Selectivity. There are three major factors contributing to the effectiveness of selection of herbicides - plant characteristics, herbicide characteristics, and the environment characteristics.

a. Plant characteristics.

(1) Genetic inheritance.

(2) Age. Older plants are more tolerant than younger plants.

(3) Growth rate. Chemical is more effective in fast-growing tissue.

(4) Morphology. Deep root systems are more tolerant than shallow systems. Vulnerable growing points on some plants are protected by the leaf canopy (i.e., cereals) whereas in others (broadleafs) the points are exposed. Leaf properties aid in selection process - chemical drops bounce and roll off upright leaves but are captured by wide, horizontal leaves.

(5) Physiology. Some plants absorb and translocate chemicals better than others.

(6) Biophysical. Some plant cell walls may absorb the chemical, reducing translocation.

(7) Biochemical. Some plants may change a harmful chemical into a harmless one, others may do just the opposite.

b. Herbicide characteristics

(1) Molecular configuration. There is a vast array of chemical combinations available to produce a specific property.

(2) Formulation. Solid particles bounce off the foliage and drop to the ground whereas liquid particles adhere to the foliage.

(3) Application. Shielded or directed spray methods are sometimes used for selectivity by the applicator.

c. Environment characteristics.

(1) Soil type and amount of rainfall determines actual location of herbicide in the soil.

(2) Temperature controls the rate of plant processes and growth.

5. Chemical Formulations and Applications. The factors influencing the selection of herbicide formulations are the same as those listed previously for insecticides. Granular formulations play a greater role with herbicides than with insecticides because many herbicides are absorbed by the roots or are applied in the soil near the germinating weed seeds. Highly volatile pre-plant

TABLE 5-12

WEED CONTROL IN AGRICULTURAL CROPS
(USDA WEED CONTROL GUIDE)

Chemicals	Formulation (see footnote)	Application
Amiben	G, WML, WSC	Grasses, Lambsquarter, pigweed, ragweed, others.
Amitrole	WSP	Bermuda grass, Canada thistle, cattails, poison ivy, others.
Atrazine	WP	Germinating weed grasses, broadleaf weeds, applied preplant, soil incorporated.
Diquat	WS, WSa	Certain aquatic weeds, general contact herbicide, deactivated in soil.
DNBP	EC, G	Germinating and established broadleaf weeds and grasses.
Methyl Bromide	Compressed Gas	Soil fumigant, controls weeds, seeds.
Paraquat	WML, WS	General contact weed killer.
Propazine	WP	Germinating broaleaf weeds and grasses.
Simazine	G, WP	Germinating annual broadleafs and grasses, long residual action.
Trifluralin	EC, G	Germinating annual broadleaf weeds, and grasses.
2, 4-D	EC, WML, WS, WSa	Germinating and established annual broadleaf weeds.
2, 4, 5-T	EC, WML, WS, WSa	Broadleaf weeds.

Formulation Code:
EC - Emulsifiable Concentrate
WML - Water-Miscible Liquid
WP - Wettable Powder
WSa - Water Soluble salt
G - Granule
WS - Water Soluble
WSC - Water Soluble Concentrate

(ref. 16)

herbicides are incorporated into the top few inches of the soil where they are protected from degrading elements and where they can give the most effective control. Table 5-12 lists a few of the more common herbicides used in agricultural crops and rangeland.

C. Fungicides

According to Street (ref. 18) there are three general classes of fungicides - surface protectants, soil protectants and disinfectants, and systemics. Whereas insecticides and herbicides are used primarily to eradicate the pest, fungicides are used more to protect the crop.

1. Surface Protectants. These are compounds which remain on the surface of the plant and kill or inhibit the pathogen before it enters the plant. Street lists the requirements for effective control by these compounds:

a. must be applied uniformly over the entire surface.

b. must protect without injury to the tissue

c. should adhere to plant surface without being eroded or decomposed by natural elements.

d. should be released in concentrations lethal to the pathogen during the infection period.

2. Soil Protectants and Disinfectants. Soil protectants are similar to surface protectants but are applied directly to the soil as either granular or liquid formulations. The disinfectants are volatile fumigants applied to the soil as liquids, granules or gases to control fungi, bacteria, nematodes, weeds and insects.

3. Systemics. These kill the pathogen already inside the plant and provide protection against future infestation.

Systemics should have the following characteristics:

a. must easily permeate plant cells without injury

b. must be translocated uniformly throughout the plant

c. must resist detoxification by the plant

5.4 DOSAGES AND PARTICLE SIZES

A. State of the Art

A considerable research effort has been concentrated upon determining the quantity and the optimum particle size necessary to control pests. Although laboratory experiments can be fairly well controlled and replicated, field experiments cannot. No two field experiments are ever exactly the same because of the infinitely varying factors in meteorology, soil and crop conditions, and application and measurement techniques. Long-standing sample measurement techniques, for example, have been brought under recent criticism for their apparent inability to accurately collect deposits and correlate actual pest kill. Notable are the drop sample collection cards positioned in the wind which actually deflect aerodynamically most fine droplets, and the insect cages positioned in a field which actually collect more spray than insects in their natural habitat under leaves.

Because of these problems and the many variations in the micro-environment, it is extremely difficult to compare results of different experimenters or to correlate the response of a sample with that of the population. Field studies typically measure the gross effects of "what it takes to kill the pest plus what it takes to get the chemical to the pest", and accurate data on minimum dosage and optimum drop size to kill the pest is difficult to extract from the literature.

Skoog et al., (ref. 19) summarizes the problem with droplet size determination in the following statement:

> Any conclusion as to the optimum droplet size for most efficient control and least contamination of the ecosystem must be qualified by considering the degradation rate and physical characteristics of the insecticide formulation, feeding habits and mobility of the target insect and its habitat, and most importantly, the atmospheric conditions at the time of treatment.

Akesson and Yates (ref. 20) also point out the dilemma regarding aerial application:

> ...the final particle size composition adopted for any aircraft use will have to be a compromise between the optimum for maximum-recovery swath width, penetration of vegetation, toxicity to pests and minimum damage to food, fish and other wildlife organisms.

and

> ...with present limitations of atomizers, there is no specific drop size best suited to all the conditions surrounding even a given insect.

B. Literature Review on Particle Size

As early as 1942, Smith and Goodhue (ref. 21) found that greater mortality of the Mexican Bean Beetle was obtained with smaller dust particles of Paris green even though larger total amounts were ingested with larger particles. Their particles ranged from 1 to 22 μm. This points out that finer particles are more readily soluble in the insect. They also cited prior research which indicates that particles smaller than 15 μm were most effective for insect kill.

Moore (ref. 22) in the mid-1960's stated that with the spraying of the spruce budworm in forests only drops smaller than 50 μm consistently reached the larvae. Drops of 1 μm size can reach the tree crowns and larvae through atmospheric transport and diffusion.

Mount et al. (ref. 23) in 1970 found that droplets in an ultra low volume spray between 10 and 15 μm were most effective for mosquito control. Akesson and Yates in 1974 (ref. 20) underscored the importance of drops 75-100 μm for killing by contact mosquitoes and locusts. For ingestion, they recommend drops smaller than 25 μm. For locusts flying in air, they recommend drops 60 to 280 μm and for the tsetse fly in the forest canopy, drops 25 to 50 μm. Wilson (ref. 13) in 1977 stated that droplets on mosquito wings in the range of 2 to 16 μm were more efficient than larger or smaller drops.

Hadaway (ref. 25) in 1969 stated that for general purpose a mean of about 20 droplets per cm^2 of surface is adequate for most problems of insect control, and even less is needed if a systemic is used. A drop size of 50 to 100 μm is desired for aerial application at ULV rates, taking all factors into consideration.

The National Research Council of Canada in its 1975 subcommittee report stated "at the present time, more and more researchers are concluding that drops less than about 100 μm are the most efficient in control of a pest problem."

Bache (ref. 26) in 1975 studied a mathematical model of aerial dispersion of spray over cotton and concluded the maximum drop size should be 60 μm. Wilson in 1977, summarizing past research, posed the paradox that the small particles that can drift the furthest are the ones having the greatest potential for effective control. He also summarized that total volume of insecticide can be greatly reduced with the use of smaller drops.

To summarize:

1. Particle size is more important with insecticides than with herbicides.

2. The smaller the particle, the more efficient it becomes in insect control.

3. The smaller the particle, the more efficient it becomes in foliage penetration but this reaches an optimum size.

4. For efficient insect control, particles should be smaller than about 50 μm. For ingestion insecticide particles should be smaller than 25 μm.

5.5 COMPARISONS OF CHEMICAL FORMULATIONS

An understanding of the biological interactions with chemical pesticides is further grounded on the knowledge of the form in which the chemical can be applied to do the job. This section deals with the three main formulations: water-based liquid, waterless liquid, and solids and compares them with respect to their effectiveness in pest control.

A. Water-Based Liquid

Water-based liquid spraying is the most common form of pesticide application. Water is used to dilute the active chemical so that the total volume of liquid applied is sufficient to produce acceptable accuracy of metering and dispersion by the applicator and acceptable uniformity of distribution on the target area. These can take on the form of a solution, emulsion, or suspension.

The advantage of using water as a chemical carrier are that it is:

1. readily available
2. inexpensive
3. non-toxic
4. chemically inert
5. sticks to foliage, where solids do not

The disadvantages are:

1. plant leaf cuticles and insect skins are generally water-repellent, requiring the addition of surfactants to the mixture to aid in wetting and sticking to the plant.
2. many pesticides are chemically incompatible with water, requiring the addition of surfactants to increase stability of the chemical oil-water mixture.
3. many chemicals cannot be produced as liquids, but are applied as suspensions requiring constant stirring.
4. water evaporates quickly, aggravating the drift problem.

B. Waterless Liquid

ULV spraying techniques were developed 20 years ago primarily for flying locusts, wherein extremely low rates of undiluted chemical were entrained and suspended in the air through which the locusts would fly. This was later applied to crop spraying to reduce the amount of material handled and thereby reduce costs.

The advantage of spraying waterless chemicals are:

1. the oily chemical liquid adheres better to the plant leaf cuticle or the insect than does water.

2. oil will not evaporate like water, nor coalesce after drop formation.

3. no emulsifying or wetting agents are needed.

4. easier material handling due to less weight, no mixing.

The disadvantages are:

1. for effective coverage at low rates, small drops must be applied, increasing the drift hazard.

2. atomization and dispensing equipment is not accurate enough.

C. Solid

Granules. Granular applications have grown in importance in recent years. Soil insects are controlled this way, preemergence herbicides are in this form, as are some systemic chemicals. Volatile herbicides are formulated into granules and incorporated into the soil for maximum effect. Other granular herbicides are merely dropped on the ground after the crop has germinated but before the weeds have gotten their start.

Advantages of granules:

1. provide physical selectivity where particles bounce off non-target plants and reach the target soil for germinating weed seeds.

2. effectively settle to the bottom of ponds - which liquid drops are unable to do.

3. provide more residual effect than liquids.

4. simpler application process - no need to mix with water, calibration made simpler.

5. particles are stable and do not evaporate or coalesce.

6. particle sizes can be closely controlled in manufacture, and particles are less sensitive to aerodynamic conditions producing drift.

7. application equipment is less expensive than liquid spray equipment.

8. granules are less toxic to humans.

Disadvantages of granules:

1. weight and bulk for materials handling is high with low percent concentrations.

2. ground interactions produce an additional set of soil variables further complicating the system.

3. higher cost per hectare with present formulations and applications techniques.

4. granules produce discrete chemical point sources on the ground which may have to rely on rainfall to spread out the chemical uniformly, whereas liquid sprays more naturally have a tendency to spread.

5. except for fumigants or systemics, granular chemicals cannot reach insects on the foliage.

6. existing granular metering devices are inaccurate at very low rates.

Controlled Release Capsules. This technology has been revitalized recently and shows considerable potential in pesticide application. A recent update of the state of the art is found in reference 27.

Chemicals are encapsulated physically either inside spherical membranes or are sandwiched between two sheets of permeable material. The chemical diffuses as a vapor through the membrane at a predetermined rate over a predetermined length of time. Another approach is the use of long hollow filaments filled with chemical, whereby the chemical moves by capillary action and vapor pressure out of the end of the filament. The rate is controlled by the diameter of the filament, the length of time by the filament length.

Advantages of controlled release capsules are:

1. chemical provides control over an extended period of time, rather than a short-lived spurt.

2. less total chemical needed for a particular application (one claim states amount applied can be as low as 1/10 of conventional amounts).

3. few applications per season (it is possible to set control for entire season).

4. chemical is not readily degraded by natural elements.

5. chemical is safe to handle, and the environment is protected from the chemical by the encapsulations.

6. outside dimensions can be closely controlled in manufacture.

Disadvantages are:

1. technology not yet well developed.

2. higher cost initially for the material.

3. release inaccuracy may produce undesirable residual effects beyond intended time period.

The potential of this type of application is underscored by Shaw and Jansen in reference 28:

> The effectiveness of most herbicides is reduced because of inadequate residual activity. In order to overcome these limitations, initial applications are usually higher than needed. We shall need to develop herbicides with controlled release characteristics. These would enhance the release of active moieties uniformly, and over predetermined periods of time. In fact, the successful development of this technology would revolutionize chemical weed control.

5.6 FACTORS INFLUENCING TRANSPORT OF CHEMICALS TO TARGET

Chemical weed and insect control is not only dependent on the interaction between chemical and the target pest, but also upon how the chemical gets into and through the target area. This section deals with the factors influencing the particles from the time they leave the dispersal system of the aircraft to the time they contact the target pest.

A. Air Turbulence

Aircraft wing tip vortices, propeller slipstream, and downwash have a considerable effect on the trajectory of the particles, especially those smaller than 100 micron diameter. The wing tip vortices carry the outboard particles out of the swath laterally and propel them up above the airplane. The propeller slipstream creates a disturbance in the plane of the propeller, skewing particles into an asymmetrical pattern. Whereas airplane wake has a substantial but temporary effect on particle transport, natural wind action presents a sustained effect on particles. Although wind is reduced significantly below the crop canopy, it plays a major role above the canopy in particle drift onto non-target areas. This is undesirable for cropland, but is desirable in large-area applications such as forest land.

B. Temperature and Relative Humidity

The primary effect air temperature and relative humidity have on particle transport is the direct effect on water droplet evaporation, which in turn affects the size of the droplet, therefore, the aerodynamic and gravity forces on the droplet, and finally its trajectory.

The combined effects of temperature, humidity, original drop diameter, and time in transport are quite complex. The transport time depends on vortex strength, wind, and height of release; and the diameter and mass of the drop are changing constantly. Figure 5-2 adapted from an article by Warren (ref. 29) shows the relation of spray drop size to drift at different wind speeds based on theoretical fall rates for terminal velocities and no change in drop size. This figure emphasizes the necessity of keeping drops larger than 150 to 200 μm to minimize the effects of drift.

Figure 5-3, also excerpted from Warren, shows the effect of relative humidity on drift for different drop sizes, taking into effect evaporation. This points out that drop sizes need to be 200 μm or larger to reach the target, even with mild wind. Another way of looking at evaporation effects is looking at the life of a drop of pure water in Table 5-13, or comparing terminal velocities of different size droplets in Table 5-14.

TABLE 5-13

LIFE OF A DROP OF PURE WATER (SECONDS)

Size μm	Life @ 20^0 C *80% R.H.*	Life @ 30^0 C *50% R.H.*
200	200	56
100	50	14
50	12	3

TABLE 5-14

TERMINAL VELOCITY OF WATER DROPS

Size (μm)	1000	500	100	50	10	5
Terminal Velocity (cm/sec)	400	210	27	7.3	0.3	0.08

C. Micrometeorology

Recently, more emphasis has been placed on studying the importance of temperature gradients affecting particle transport. Temperature gradients become the dominant influence on very fine particles (less than 50 μm in diameter) in the absence of wind. Akesson and Yates in 1974 (ref. 20) stated:

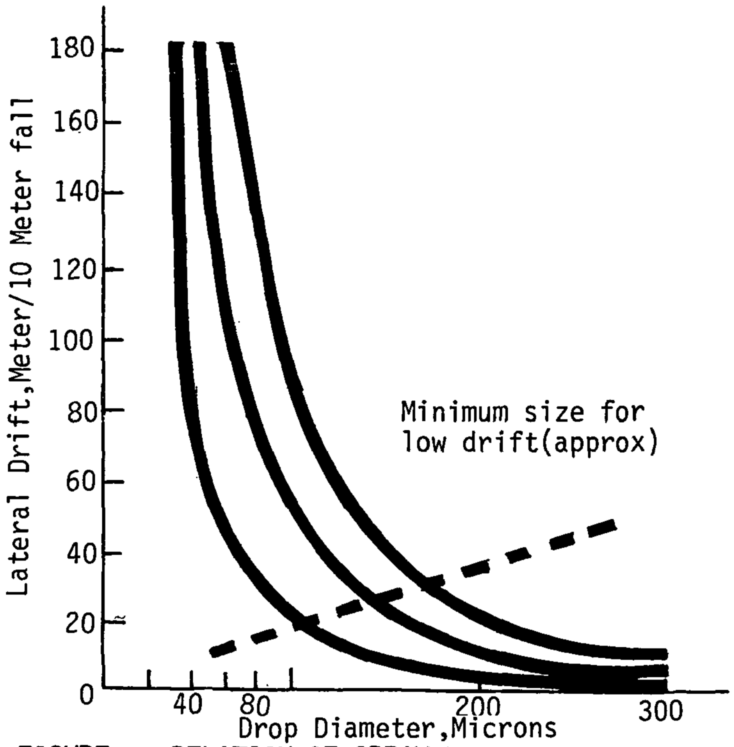


FIGURE 5-2 RELATION OF SPRAY DROP SIZE TO DRIFT AT DIFFERENT WIND SPEEDS

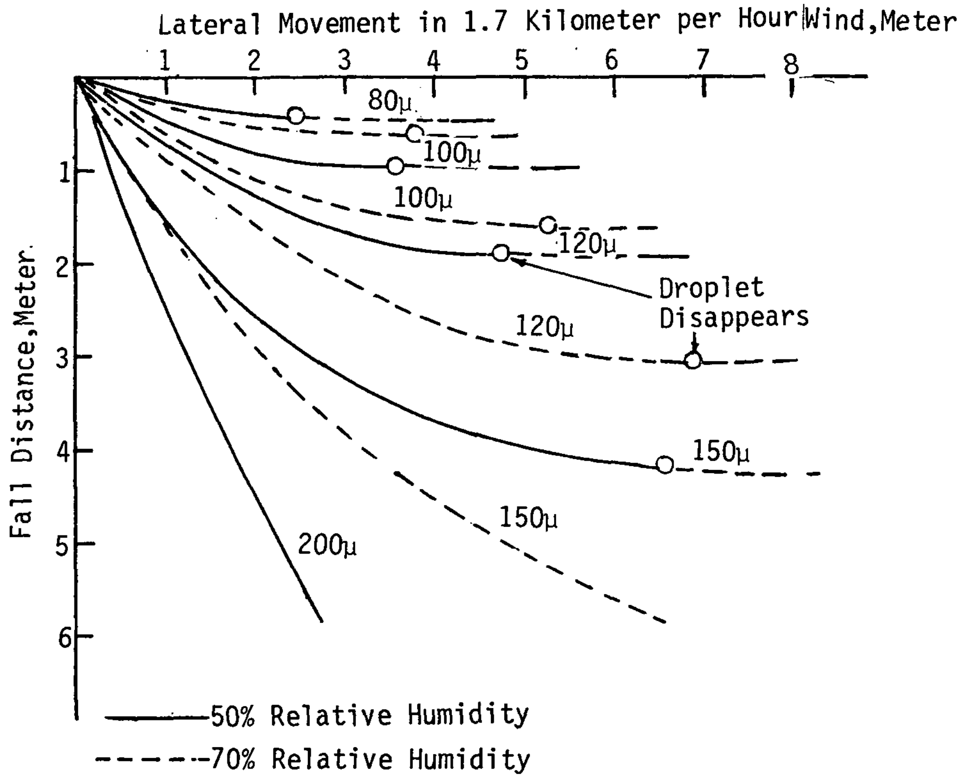


FIGURE 5-3 EFFECT OF RELATIVE HUMIDITY ON LATERAL MOVEMENT OF SPRAY DROPLETS IN A 1.7 KILOMETER PER HOUR

Probably the most universally involved and yet the least understood is the role of meteorology and its effect on the dispersion, diffusion and deposit of released materials and on efficient application. Microweather becomes the single most important determinant of the ultimate fate of an aerosol smaller than 50 μm.

Figure 5-4 graphically displays the changes in temperature with height above the ground at different times of the day. Stable air conditions are induced usually by cooling of the air close to the surface from radiation in late afternoon and through the night. This starts with a normal lapse condition (considered a gradient of 0.58°C per 100 m elevation) at around 5 p.m. This then moves to an isothermal condition where temperature is essentially constant up to a certain elevation. At around 8 p.m. a temperature inversion develops where, up to a certain elevation, the air close to the ground is cooler than the air above. This inversion becomes stronger throughout the night until about 4 a.m., when the trend reverses.

Under stable air conditions, especially under an inversion, essentially no vertical air movement and mixing occurs, but the predominant air movement, if there is any, is in a horizontal direction. The colder, denser layers at the bottom do not mix with the warmer, less dense layers at the top. Thus any fine particles dispersed into the air will remain suspended for long time periods, falling slowly but being carried horizontally off target as drift. Any slight wind at this time will greatly add to the drift problems.

Returning to Figure 5-4, the stable condition becomes weaker throughout the morning, reaching a normal lapse condition around noon. This is due to solar heating of the earth's surface. Throughout the afternoon the temperature gradient becomes an unstable condition wherein the hot earth's surface essentially "boils" the air above it. This produces considerable movement of vertical air containing the falling particles over the target area. Rising hot air currents will carry very fine particles (less than 30 μm) aloft where they become greatly diffused and generally degraded by photo decomposition.

This unstable condition reaches a peak at a super adiabatic level at around 2 p.m., whereupon it reverses, becomes weaker throughout the rest of the afternoon, and passes through a normal lapse condition once again at around 5 p.m. Researchers have suggested that spraying chemicals by air early in the morning, where the air is still, may not be a good time due to this potential drift hazard. Also, several have recommended that particles should be larger than 200 μm to overcome the influence of micrometeorological conditions.

D. Plant Morphology

The structure and density of the plants in the target area influence the trajectory and deposition of the chemical particles. The leaf structures produces a "screening" effect for falling drops, and the air turbulences around leaves and stalks complicate the trajectory of very fine airborne particles. Evans et al. (ref. 31) in 1965 sampled amounts of fungicide deposited on the leaves of potatoes and found that the top leaves collected significantly more spray than the bottom leaves.

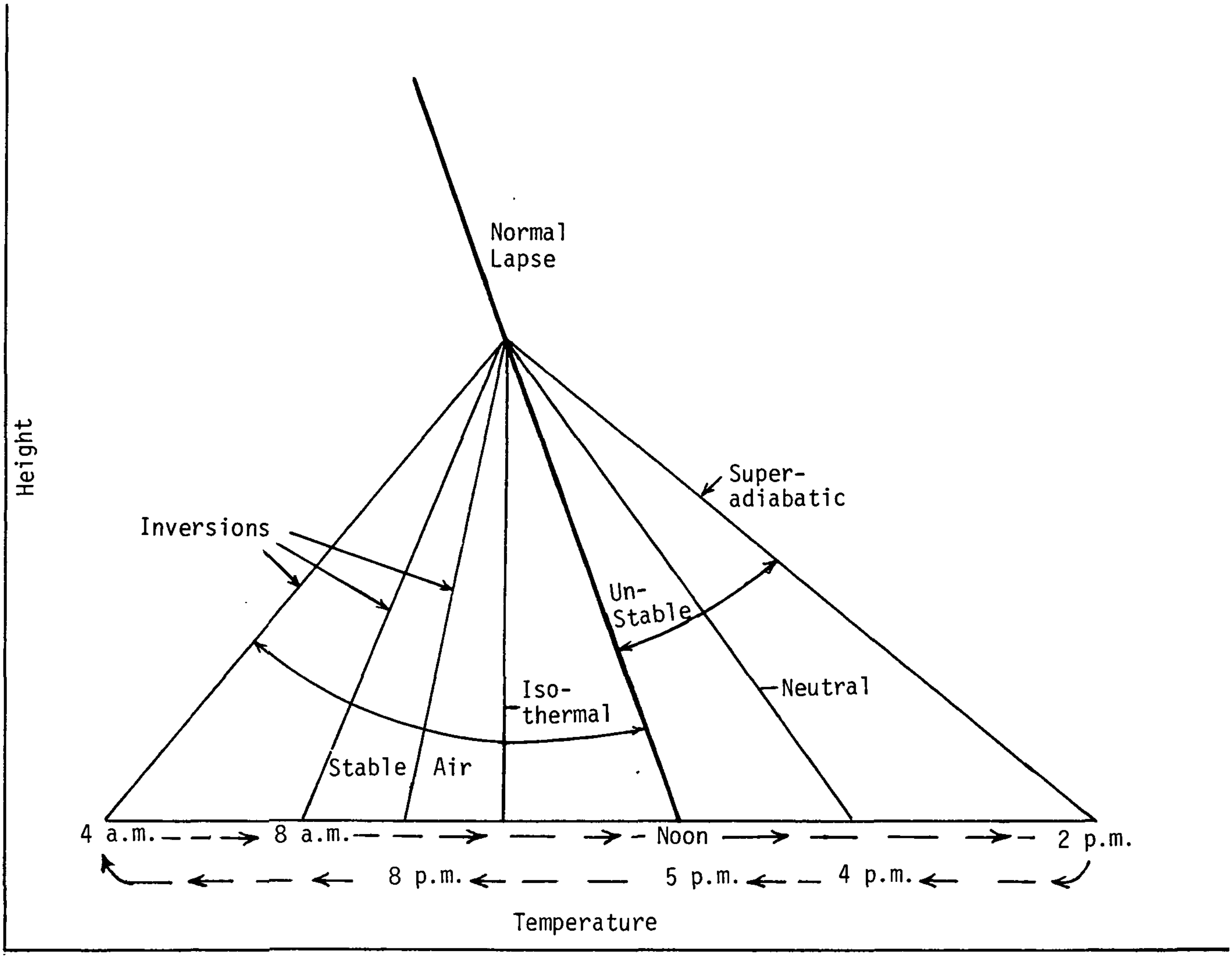


FIGURE 5-4 TEMPERATURE GRADIENTS AT DIFFERENT TIMES OF THE DAY

Hadaway (ref. 25) discusses the deposition mode of various size drops. Drops larger than 100 μm are not greatly airborne but fall under the influence of gravity and deposit predominantly on the upper surfaces of the foliage. Drops in the range of 50 to 100 μm fall by gravity when wind is low but are more influenced by aerodynamic forces when wind is medium to high. These then have more of a tendency to be carried around leaf tips and stalks and to collect on the underside of leaves as the wind becomes stronger and more turbulent. Drops from about 10 to 50 μm seem to be optimum for underside deposition. However, drops smaller than about 10 μm are so entrained in the air currents they deposit on only small objects and may find very little deposit on leaves and stalks.

This was underscored by Wilson in 1977 when he stated droplets larger than 150 μm fall to the ground or deposit on the outer foliage. Drops 120 to 150 μm are rapidly screened out by all foliage. Smaller drops pass foliage with increasing efficiency and are capable of reaching all parts of the plant. Drops 20 to 40 μm are found on the underside of the leaves.

E. Soil

Granular insecticides and herbicides which are incorporated into the soil are influenced to a considerable extent by the very complicated interaction of the many soil variables. According to Klingman and Ashton (ref. 17) there are at least ten different soil variables of major importance. The granules in the soil constitute a finite number of point sources from which the chemical has to spread outward by diffusion and mass flow. This movement is a function of soil conditions, weather conditions, depth of granule placement, chemical properties, and time.

The soil aids greatly in extending the residual effect of chemicals which otherwise would decompose in the air before doing their job. Factors affecting chemical persistence in the soil are soil microorganisms decomposition, soil chemical decomposition, absorption on the soil colloids, leaching, volatility and photo decomposition. For instance, soils with high clay content will tie up the chemical, rendering it useless, whereas some sandy soils are so coarse that even a mild rain will wash (leach) the chemical down out of the root zone.

F. Systemic Action

Systemic action, explained earlier in this report, is an extremely complex mechanism involving the plant physiology and chemistry. Much research is needed to fully understand this process.

5.7 REGULATORY OBSTACLES TO CHEMICAL DEVELOPMENT

It is unlikely that the chemical industry will develop some of the needed chemicals for several reasons: cost, time, and government regulations. The 1977 annual report of the National Agricultural Chemical Association indicates industry expenditures for research and development of $195 million (ref. 22, p. 8). This expenditure represents a 25 percent increase over 1975. What the expenditures went for is illustrated in Table 5-15.

TABLE 5-15

INDUSTRY R & D EXPENSES BY PURPOSE AND AS A PERCENT OF TOTAL R & D EXPENSE

New Products	Product Expansion	Registration Product Defense
$131,000,000	$38,000,000	$26,000,000
67%	20%	13%

(ref. 21, p. 9)

These R & D costs represent 7.6 percent of the total sales of reporting companies (ref. 22, p. 11). The time factor also discourages the development of new products. The average elapsed time from discovery of a new compound to final registration in 1976 was 74 months - or 31 percent of the patent time (ref. 22, p. 8).

Federal regulations requiring proof of product safety prior to marketing are a difficult, if necessary, burden. Industry expenditures for field plot testing to demonstrate product safety (for purposes of registration) exceed the cost of synthesizing the products. In 1976 field plot testing cost $4,000,000 (ref. 22, p. 9). When viewed as a percentage of industry sales the cost is 1.8 percent. This figure is not inherently prohibitive; however, when combined with the myriad of recent regulations the costs are a disincentive to the development of new products.

5.8 SEEDING, PLANTING AND FERTILIZING

Distribution of some seeds, seedlings, and fish by air is routine. The promise of double cropping in temperate zones and no till farming suggests a bright future.

Seeding Rice

Rice seeding by air has become common practice in many parts of the world. In fact, most operations involved with rice, except irrigating and harvesting, are performed by air. As early as 1952 farmers indicated that air seeded and treated rice averaged about 1.25 cubic meters per hectare (16 bushels per acre) more than that handled by ground applied methods (ref. 32). Over a nine year period the average increase was 1.17 cubic meters (33 bushels) per hectare. The net advantage in this case amounted to more than $78.73 per hectare ($31.49 per acre)(ref. 33).

Increased involvement of ag-air in rice production will depend largely on the extent to which flying services are able to increase the effectiveness of the work done at rates that are reasonable. In the case of rice, it appears that seeding by aircraft is the only feasible method.

Seeding Soybeans

Double cropping, which is growing two crops on the acreage the same year, is gaining in popularity in the midwestern states. During 1976, midwest farmers double-cropped an estimated 6,000,000 hectares (15 million acres). About 10 percent of the 1976 soybean acreage was seeded after a small grain. In some cases the seeding was done by air prior to the small grain harvest.

For soybeans, as in the case of many other crops, timeliness of planting is essential in order to take advantage of the most suitable growing weather. In general, the earlier one plants soybeans the better the chances are of higher yields. Usually it takes about 90 frost-free days to mature a 2.5 cubic meters / hectare (30 bu/acre) crop of soybeans.

There has been some practice of seeding the soybeans in oats, wheat, etc. prior to harvest of the small grain crop. This allows the beans to germinate and begin growth in moister soil and gains frost-free days. Harvesting of the small grains will provide straw and chaff which act as mulch for the soybeans which had been seeded earlier. This process of broadcasting seed in an already standing crop is called "relay cropping" which amounts to double cropping (ref. 34).

Seeding Small Grains

Other examples of relay cropping occur where farmers have seeded rye, wheat or barley in corn. This system is used to gain pasture for cattle during the winter, to prevent soil erosion, or to seed the small grains early enough so that pasture as well as grain are obtained from the same acreage. This method is especially useful where the corn is chopped for ensilage, a practice which exposes the soil to wind and soil erosion during the winter when freezing and thawing loosen the soil.

Seeding Grasses

Aerial application of grass seed differs somewhat from seeding of crops which have heavier seeds. Grass seeds are more likely to be affected by the wake of the aircraft and winds if the application is performed on a windy day. Seeding rates per hectare are usually relatively small.

Special application or dispersal systems may be necessary in order to be able to meter accurately the low seed flow from the hopper. Experience has shown that the cost of seeding by air is comparable to that of ground methods but is faster, and in many cases where the terrain is rough or brushy, is the only method to use.

Planting of Tree Seedlings

Manual labor for the reforestation of land in the U.S.A. has become increasingly expensive and hard to obtain. In the southern pine region 6,000,000 hectares (15 million acres) were planted from 1947 to 1967 (ref. 37). It is estimated that the annual reforestation goal for the Pacific Northwest should be at least 100,000 hectares (250,000 acres((ref. 36).

With the increase in cost and reduced availability of labor, other means of reforestation must be explored. Aerial planting of seedlings has been done using balloons, helicopters, and airplanes.

The most successful of recorded attempts to plant seedlings by air was reported in April 1971. 1800 seedlings were specially prepared so that the roots would strike and penetrate the soil. Preparation of the seedling included planting them in a mold which was filled with soil. The soil-mold mass was then wrapped in polyethylene film and frozen. After freezing they were placed in short pieces of five cm polyvinylchloride pipe to which fins had been attached. These specially prepared seedling "bombs" were designed so that they would fall vertically and strike the earth with the root system penetrating the soil. The frozen "bombs" which weighed 180 grams, were dropped from a distance of 170 meters (400 ft) and penetrated the soil 16.5 cm (6.5 inches). Splitting of the plastic bombcase on impact permitted root-egress. This method is in effect a balled root planting.

The aerial planting cost is seven cents per seedling; ground planting cost is eight cents per seedling. The aerial planting rate is 160,000 seedlings per day per airplane; ground planting rate is 700 seedlings per day per man.

Stocking Fish

Many resevoirs and lakes are located in rough terrain where ground access is limited. Here aerial stocking of fish may be the most economical method. Advantages of aerial stocking are:

(1) Fish can be distributed over the entire area.

(2) The distribution can be accomplished in a short length of time.

(3) Transport time is a lot less than by ground.

In Montana the practice of aerial stocking has been carried on for many years in areas which are inaccessible by roads (ref. 40). In 1956 more than four million fish were distributed by aircraft in the Tiber resevoir. A special tank was constructed to hold approximatelv 225 liters (60 gallons). Ice was used to maintain the tank temperature near 4°C (40°F) since the fish require that temperature while in transport. The water was aerated with compressed oxygen. The fish were dumped from altitudes of 60 to 90 meters (200 to 300 feet) at an airspeed of 130 kph (80 mph).

Fertilizing Rice

It has been reported that proper use of fertilizers on rice increases yields from 30 to 50 percent in southern rice areas of the U.S. (ref. 44). Since rice is grown in a wet or flooded soil, it is difficult to properly apply fertilizer by conventional ground systems. Fertilizing rice by ag-air is customary in the U.S.A., as well as in many other countries.

Fertilizing Wheat

For high yields and maximum protein content, wheat requires a great amount of nitrogen as well as plenty of moisture (ref. 45). However, if moisture is insufficient, it is not economical to apply high fertilizer rates on wheat because the plants cannot use the nutrients. Farmers frequently wait until winter snow or spring rains produce a sufficient amount of moisture to ensure that fertilizer application will be beneficial. Should the snow or rains produce sufficient moisture by March or April, it is then feasible to quickly apply nitrogen to enhance the yield and quality of grain. At this time the wheat plant has developed a substantial growth and has perhaps produced stems which would be partially damaged or destroyed by conventional ground application. Frequently, after spring rains or after heavy winter snows the soil is soft or muddy and will not even permit the use of ground equipment.

Ag-air is advantageous in distributing fertilizers on wheat because of its covers vast acreages in a minimum of time, it does not damage the growing crop, and its operation is not inhibited by wet, soft ground.

Fertilizing Soybeans

With the development of new foliar fertilizers, the trend is toward foliar applications. The foliar fertilizers are applied on the plants about the time the pods begin to fill. At that time the plant has grown rather tall and bushy which tends to make ground application difficult, and soil compaction under ground equipment tends to lower yield. Ag-air application of foliar fertilizers can be done quickly and with no detrimental effect due to plant injury or ground compaction.

Forest Lands Fertilization

Forests are also fertilized by air (ref. 46). It would be impossible to utilize regular ground methods to fertilize forests after the trees are planted; however, though the use ag-air methods, the operation can be dealt with economically and effectively. In 1972, the Weyerhauser Corporation treated 150,000 acres and almost doubled that amount in 1973.

Range Land Fertilization

Range and grass lands are also areas where the terrain and brush and trees make it necessary to use ag-air in fertilizing.

5.9 DISPERSAL SYSTEMS

The discussion of dispersal systems in this section will include all of the equipment necessary to distribute materials from aircraft, including ground support equipment, but not the aircraft itself or the navigation system. This separation is possible because airborne dispersal equipment has normally been of the add-on type rather than an integral part of the aircraft.

Two general types of materials, solids and liquids, are dispersed from aircraft. Solid materials, such as fertilizers and seeds, usually require the aircraft to carry its maximum payload in weight and to make frequent landings for refill. This requires a landing strip near the field and special ground support equipment to minimize loading time if efficient operation is to be expected. Pesticides and herbicides, are usually dispersed as liquid droplets. This requires different equipment from that used for solids. Payloads vary from that for low volume (ULV) spraying where the aircraft payload is insignificant (as little as 55 millilitres per hectare is required in mosquito control) to heavy payloads of solid materials (several hundred kilograms per hectare). All this adds up to a great variety of equipment needs to accomplish the ag-air mission.

Early Development

The earliest dispersal method was simply to dump powder over the side of an open cockpit and let it be spread by the propeller wash and wing wake. The next step was to cut a hole in the bottom of the airplane for a hopper outlet and control the rate of dispersal by an operator turning a crank. Modern dispersal systems have evolved from these early attempts largely by cut-and-try methods. Development has been through short term and low budget efforts by individuals and small companies.

State of the Art

Today's equipment does a remarkable job, but there is a great need for improvement. The present state of development of dispersal system technology has been summarized in various publications (e.g., ref. 47 and 48). Spreader technology for dry materials is rather primitive. Ram air and rotating vane spreaders are the most common. Neither of these is acclaimed for its effectiveness in providing uniform distribution and accurate flow rates. Spreader systems depend heavily on the mixing action in the aircraft wake to achieve some tolerable level of uniformity in distribution. Typical spreader installations are discussed below:

(1) Ram air apreaders. A schematic of a typical ram air spreader is shown in Figure 5-5. The hopper is mounted inside the aircraft and the spreader is mounted below the fuselage directly in the propeller wash. Seeds or granules are metered through the gate at the bottom of the hopper and fall directly into the air stream inside the spreader. The material is accelerated by guide vanes so it will spread out as it falls to the ground. A typical ground distribution pattern is shown in Figure 5-6. The swath width is generally a little

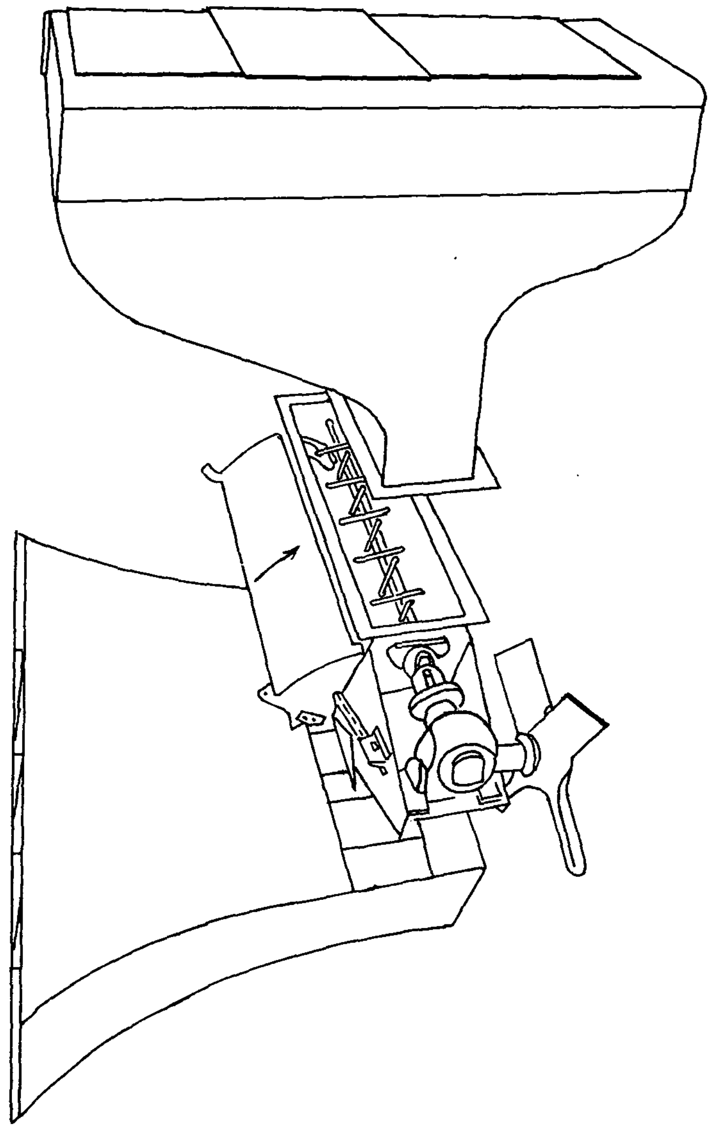


FIGURE 5-5 TYPICAL RAM AIR SPREADER, (REF. 49)

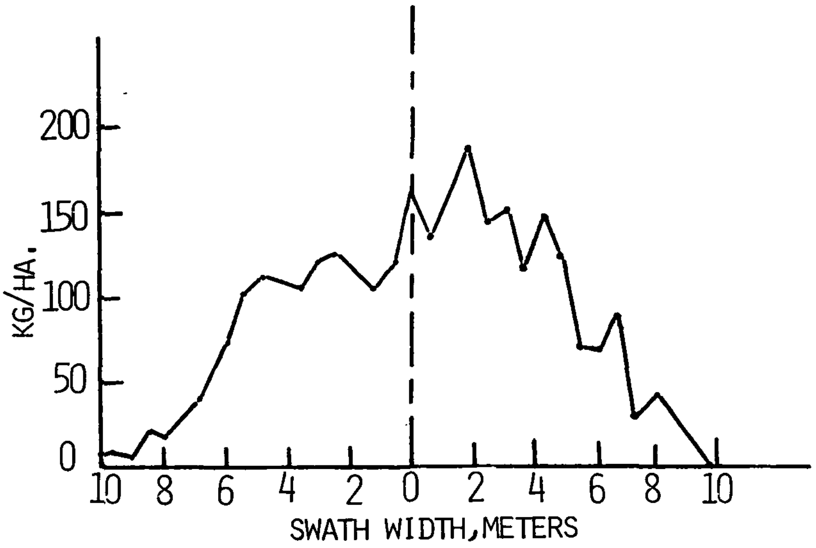


FIGURE 5-6 TYPICAL RAM AIR SPREADER DISTRIBUTION PATTERN, (REF. 48)

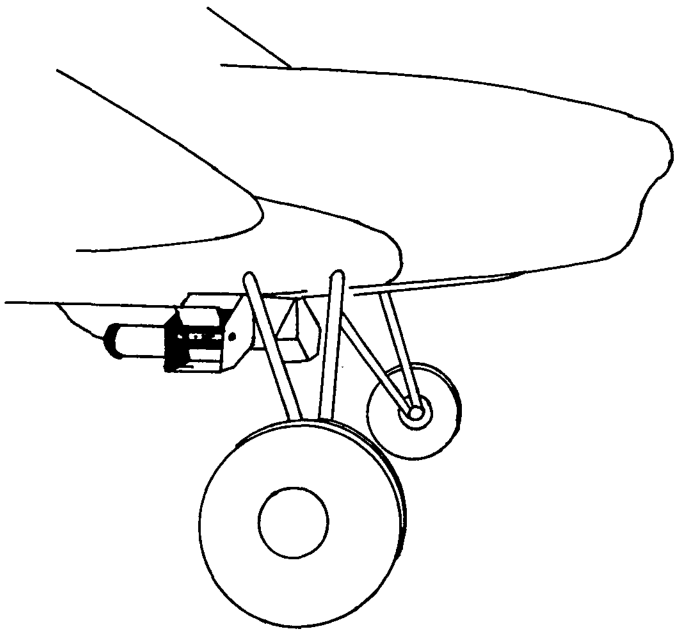


FIGURE 5-7 SPINNING SPREADER (REF. 48)

more than wingspan of the airplane. There are several models on the market and they have been adapted to various aircraft. The spreaders can usually be removed easily to free the aircraft for another job.

(2) Rotary spreaders. A schematic of one type of rotary (spinning) spreader is shown in Figure 5-7. A typical ground distribution is shown in Figure 5-8. The solid material is fed into the spinning device at a controlled rate and is ejected into the airstream by the rotating vanes. Various other arrangements are used, including flat rotating plates similar to those used on ground equipment. The swath is generally a little wider than the wing span. Rotary spreaders are more commonly used with helicopters. In some cases the hopper, spreader and power source have been packaged together and suspended by cables below the helicopter. By using two or more packages the reload time for the helicopter is minimized.

Sprayers for soluble or suspended materials have generally been of the boom and nozzle type adapted directly from ground equipment. More recently rotating cylindrical screen atomizers have been developed for aerial applications work. Some typical sprayer installations will be discussed below.

(1) Boom-nozzle sprayers. A schematic of a boom-nozzle sprayer system is shown in Figure 5-9. Typical distribution patterns are shown in Figure 5-10. This system is very common and is used for a large part of all ag-air work. The unit consists of a storage tank, a pump and a boom with spray nozzles distributed along it. Uniform controlled flow is achieved by selecting nozzle size, spacing and pump pressure.

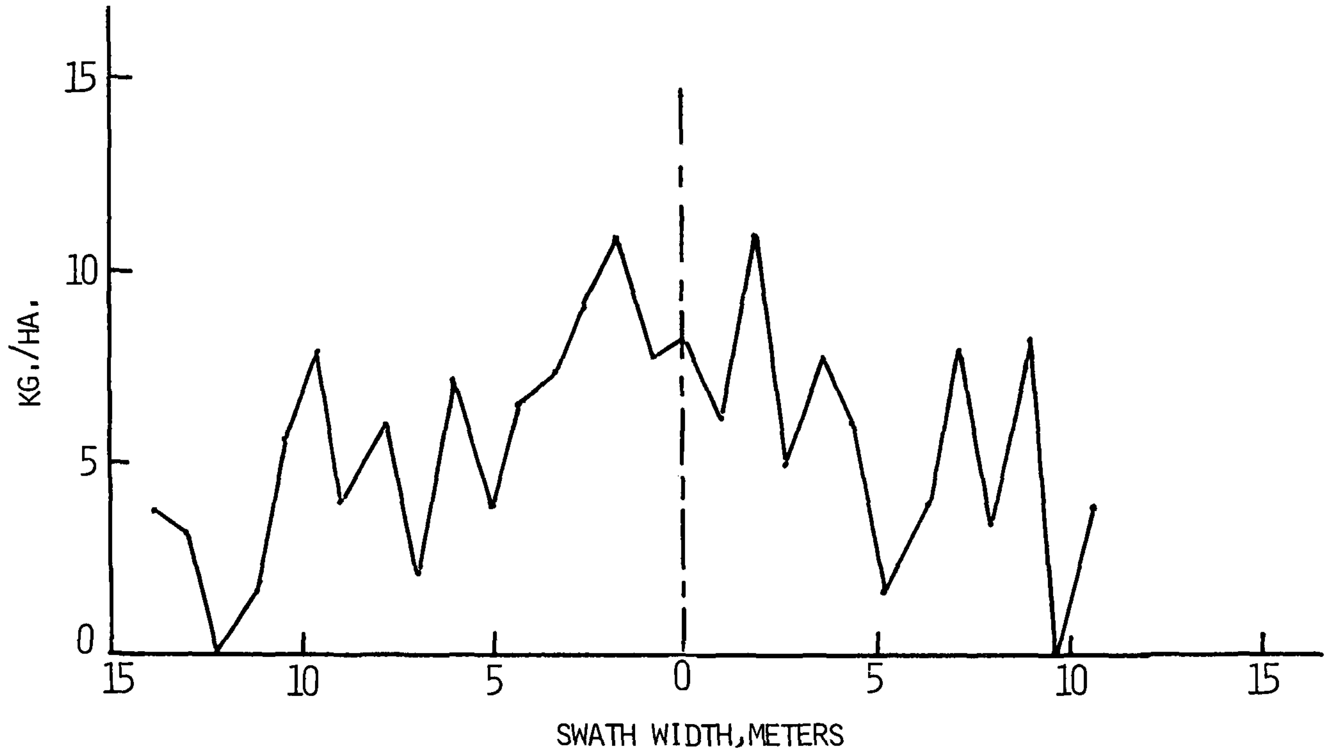


FIGURE 5-8 TYPICAL DISTRIBUTION PATTERN FROM ROTARY SPREADER (REF. 48)

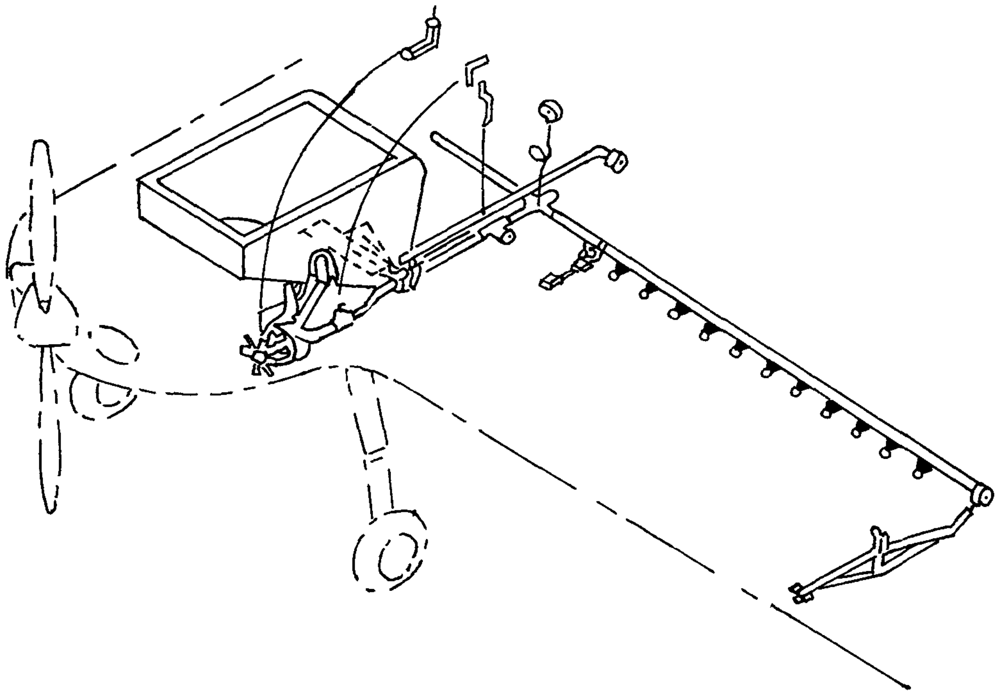


FIGURE 5-9 TYPICAL BOOM-NOZZLE SPRAY SYSTEM (REF 48)

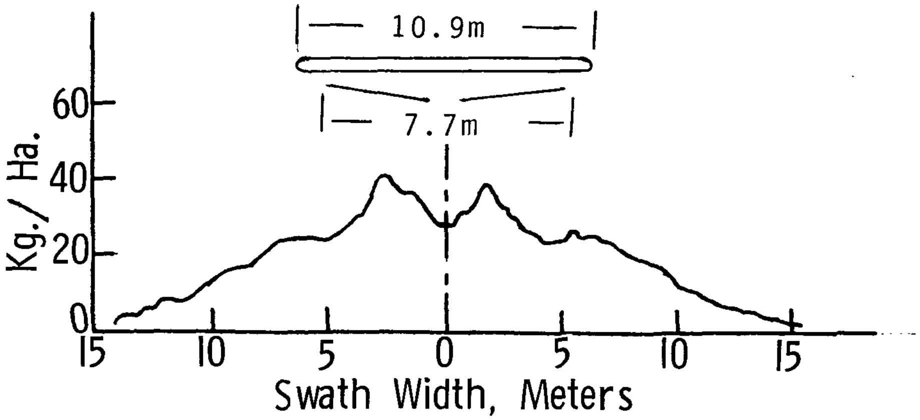


FIGURE 5-10 TYPICAL SPRAY DISTRIBUTION PATTERN FOR BOOM-NOZZLE SYSTEM (REF. 48)

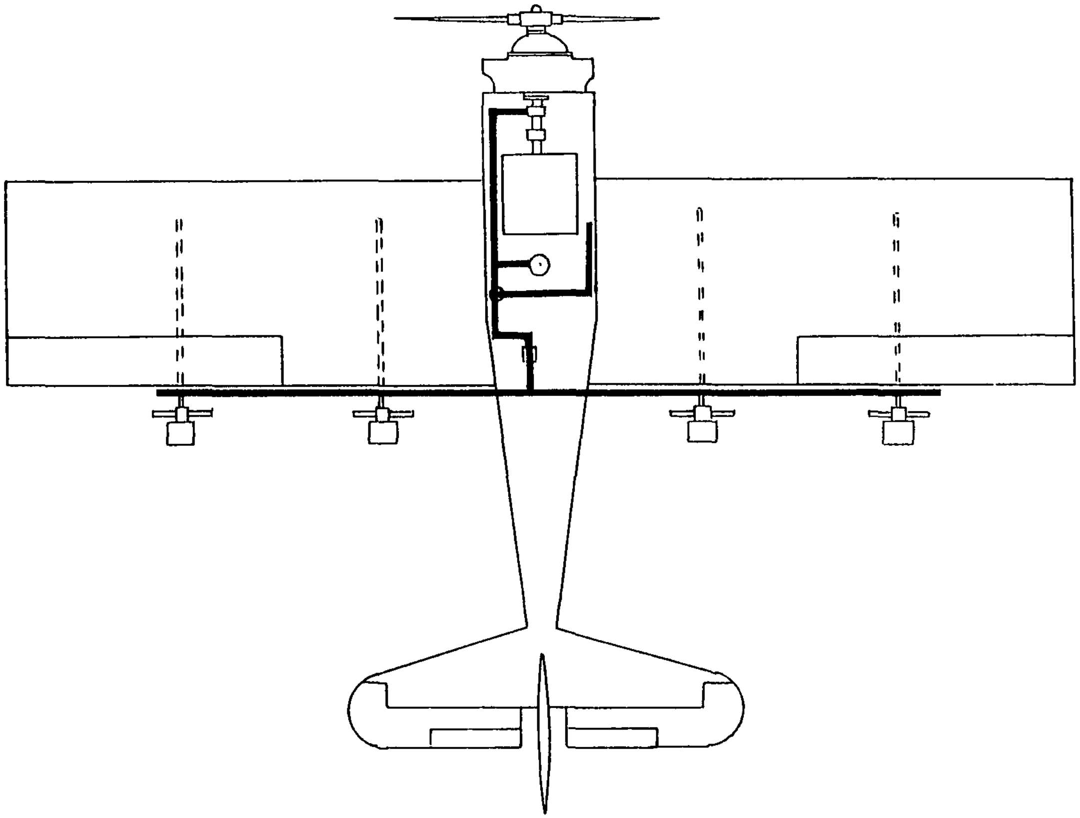
(2) Rotary atomizers. A schematic of a rotary atomizer spray system is shown in Figure 5-11 (ref. 50). It is similar to the boom-nozzle system with rotary atomizers replacing the nozzles. A typical atomizer disperses more material than a typical nozzle and therefore, they are more widely spaced. The liquid is pumped to the atomizer under low pressure, and the high speed rotating device, often a cylindrical cage or screen, breaks up the liquid into droplets. The size of the droplet can be controlled by adjusting the grid size of the screen and the speed of rotation. These devices tend to produce a narrower range of droplet sizes than nozzles. Rotary atomizers are especially effective for ULV applications such as are encountered in mosquito and other insect control. They have not found as wide a use in the medium and higher volume spraying operations, perhaps because they cost more to install. Compared to the cost of aircraft, this cost is not high.

Power to operate sprayers and spreaders is a major design consideration. Ram air spreaders extract energy directly from the airstream. Agitators for spreaders and pumps for sprayers generally are powered by propellers which also extract energy directly from the air stream. Such devices are simple and practical, and may be mounted on any aircraft, but they have high drag, are inefficient, and have inflexible control arrangements. Fixed-bladed propellers or ground-adjusted propellers are used, thus power generated in flight depends upon airspeed and cannot otherwise be controlled. In some cases power takeoff drives from piston engines and bleed air from turbine engines have been used to power pumps and vanes. Unfortunately, piston engines used in agricultural aircraft were not designed for driving any significant amount of auxiliary equipment and therefore, generally do not have sufficient takeoff power to operate sprayers and spreaders. Auxiliary engines have also been used to power pumps and vanes.

Many of the materials applied to crops, such as pesticides, are toxic and therefore require special handling on the ground for safety reasons. Wet materials often require field mixing. Equipment and procedures for handling such materials are generally the same in aerial applications as in ground applications. Bulk dry materials such as fertilizers and seeds, while not toxic, require special loaders in order to minimize the time on the ground for the aircraft. Because of the high hourly productivity and cost of the aircraft, even a small time on the ground cuts into the economic advantage of the use of aircraft. Most of the special systems for ground loading of bulk materials have been put together by independent operators.

Problems of the Industry

In recent years there have been several surveys conducted on the problems of the agricultural aviation industry (e.g., ref. 51 and 52). Several speakers, experts in their fields, have spoken on the same subject for the Summer Fellowship Program. All these sources come to the same basic conclusions on the problems related to dispersal systems. Among improvements needed are:



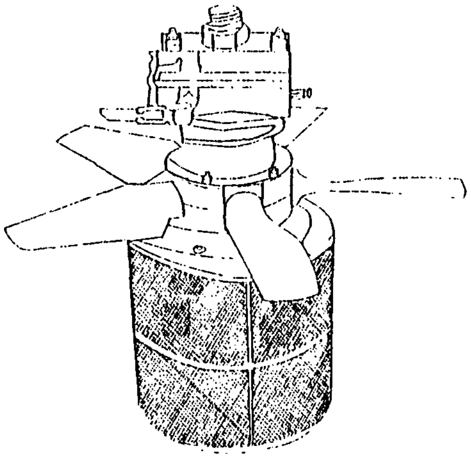


FIGURE 5-11 ROTARY ATOMIZER SPRAY SYSTEM (REF. 50)

1. Eliminate drift that occurs with small droplets and particles.

2. Obtain more uniform distribution and wider swath widths.

3. Better safety and efficiency of the operation on the ground and in the air.

It may be concluded that several factors combine to make it difficult to provide uniform coverage at prescribed flow rates without drift. A part of the problem is the hostile environment for droplets and particles in the turbulent wake of the aircraft. In particular, small particles become entrapped in the flow field and cannot be prevented from drifting far from the intended point of application. Furthermore, even when droplets of preferred size are generated by the dispersal equipment, conditions in the flow field tend to break them up into smaller particles which are then entrapped in the flow.

Another problem is the irregular and uncertain micro and macro meteorological environment into which the droplets and particles are injected. Wind is an enemy which makes uniform application of material difficult and greatly complicates the problem of drift. Even when there is no wind, but a temperature inversion exists, there is a tendency for lateral drift of small particles.

The degree of difficulty in providing proper application is increased by the rather primitive technology used in many dispersal systems. They do not provide uniform spreading or closely controlled flow rates. Add to this the difficulty of flying over a prescribed path with accuracy at precisely the correct height and the opportunities for error are seen to abound.

Some of the problems associated specifically with sprayer system design are:

1. Control of liquid droplet size.

2. Uniform distribution of droplets or particles.

3. Wider swath coverage.

4. Safer and more efficient ground equipment.

Another list of problems, such as control of the path of the sprayer or spreader, can be attributed to the design and operation of the aircraft and its guidance system. These are discussed in other sections.

Proposed Research

The best ag-air system would very likely require a new airplane, new dispersal system, and new ground equipment, all designed as a single integrated system. This should be a long range goal of ag-air research and preliminary steps should begin now. Improvement of individual components through research, however, should not be neglected while pursuing this grander goal. The solution of a number of immediate problems through component research would not only benefit the thousands of current operators but would benefit the development of the integrated system as well. We shall discuss some of the component research areas where we believe substantial progress can be made.

Dry Material Spreaders

Ram air spreaders are among the most primitive devices used in agricultural aviation. They generally have high drag, do not provide uniform distribution or accurate flow rates, and generate too narrow a swath. There seems to be general agreement that the pure ram air spreader has limited potential for further development but the simplicity of the design makes it very desirable. Particularly for the many aircraft currently in operation, an improved ram air spreader would be beneficial. A conventional spreader drops the solid particles into a high velocity airstream where the particles are accelerated, some are turned outward by vanes, and injected into the wake of the aircraft for mixing and spreading. It was reported to the Summer Design Group that Razak and Akesson are working on a new diffuser ram air spreader where the particles are dropped into a low velocity flow and turned by vanes before they are accelerated. Better distribution is expected. This is an example of the kind of research in ram air spreaders which should be encouraged. Powered spreaders have also been proposed (ref. 47 & 53), but they do not appear to have had much impact as yet.

Among the opportunities for research are:

1. Basic research on the behavior of solid particles dumped into a diffuser and injected into an aircraft wake.

2. Research on improved ram air spreaders with emphasis on drag reduction (discussed in more detail in a later paragraph) and uniform distribution.

3. Research on positive powered spreaders where an auxilliary power source augments or replaces ram air power.

4. Evaluation of alternative spreader systems, such as rotating vane spreaders, to identify possible new areas for research.

5. Research on integrated aircraft-spreader designs which utilize new aircraft design features to improve spreader performance.

Wet Material Sprayers

Boom and nozzle sprayers have reached a certain state of development largely through an extensive (and probably effective) method of cut and try. Continued improvement in nozzle design would be beneficial and should be possible. Rotating screen atomizers are at an earlier stage of their development and should have great potential for further improvement. The generation of droplets of proper size is fundamental to spray systems, therefore, droplet research should receive much attention. In addition to research on the mechanical generation of droplets there should also be more research on the effect of chemical additives for the control of droplet size. The generation of charged droplets which would tend to adhere to the target because of electro-field interaction with dispersed particles remains the greatest single problem demanding further research.

Among the opportunities for research in spray systems are:

1. Basic research on the behavior of liquid droplets injected into an aircraft wake.

2. Research on generating droplets of a given size, including mechanical (sprayers - nozzles - atomizers) and chemical (additives) technology.

3. Research on comparative advantages of various kinds of atomizers.

4. Research on sprayer design and integration with flow field interactions.

5. Research on integral aircraft-sprayer systems.

Auxiliary Power Requirements

Aircraft designed for certain performance characteristics in their regular clean configuration can suffer substantial degradation of performance when dispersal systems are attached. In particular the power required to carry and operate this equipment is no longer available for powering the aircraft. Compared to a clean aircraft, one with a dispersal system in place can have:

1. Increased takeoff run.

2. Reduced rate of climb.

3. Lower cruise speed or increased power setting to maintain a given speed.

4. Increased stall speed.

5. Reduced acceleration.

6. Increased fuel consumption and wear.

7. Impaired handling and stability characteristics.

The power increment for carrying and operating dispersal systems results from drag increases. First, the weight of the system is reflected in an induced drag increase; second, the booms and various appendages result in profile drag increases; and third, since most sprayers are powered by wind driven propellers and spreaders by ram air, the power for operating the system results in direct drag increases. The first of these can be measured directly in terms of payload loss. Given a maximum takeoff weight, the weight of the dispersal system proportionately reduces the payload of the aircraft. The power required to carry the equipment is the same as for an equivalent in payload. The power required for the remaining two components of drag has been measured for specific aircraft (ref. 54) and has been found to be significant. Table 5-16 summarizes the results of actual tests on five different aircraft. (The names and descriptions of the aircraft and dispersal system may be found in ref. 54). These results show that the power requirements for the dispersal system can be 25 to 75 percent of the power requirement for the clean airplane in level flight at the normal operating speed. (This excludes the power needed to carry the weight of the dispersal equipment).

For the systems tested, values of horsepower required for the dispersal system alone are 33-65 bhp for sprayers and 42-140 bhp for spreaders. Much of this power may be attributed to the drag. A substantial amount of this power loss could be recovered if the power for dispersal systems was available as a power takeoff from the aircraft engine, but unfortunately engines have not been developed for ag-air which can provide this power. Separate auxiliary engines would be less efficient than power takeoff but may be more efficient than current wind driven systems (ref. 55). This appears to be a fertile area for further research. Among the opportunities for research are:

1. Research on new engine designs with adequate and efficient power takeoff systems for operating dispersal systems.

2. Research on propeller driven systems to reduce drag and improve efficiency and effectiveness.

3. Research on ram air systems to reduce drag and improve efficiency and effectiveness.

4. Research on drag reduction of booms and other dispersal system attachments.

5. Research on alternate auxiliary power systems, such as auxiliary engines to replace wind driven power units.

Flow Field Interactions

Uniform downwash from the trailing edge of the wing contributes to the uniform application of droplets or particles by directing them downward and by providing a mixing action. A finite wing attached to a fuselage with a powered propeller has other flow characteristics which interfere with the downwash to provide some negative results. Wing tip vortex action, particularly, tends to entrap small particles and prevent them from falling on the intended target. The small particles remain suspended in the atmosphere for some time and depending upon wind conditions, can drift to fields other than those being treated, often with harmful effects. Wing-fuselage interference and propeller turbulence also interfere with the downwash, preventing uniform application.

TABLE 5-16

POWER REQUIREMENTS OF DISPERSAL SYSTEMS
AT NORMAL OPERATING SPEEDS

		SPRAY SYSTEMS				DISTRIBUTOR SYSTEMS			
AIRCRAFT	ENGINE RATED BHP	AIRSPEED MPH	SYSTEM BHP	% RATED POWER	% BASIC AIRCRAFT	AIRSPEED MPH	SYSTEM BHP	% RATED POWER	% BASIC AIRCRAFT BHP
I	135	90	41	30	66	90	48	35	77
II	235	95	54	23	45	95	74	31	65
III	235	95	33	14	23	95	42	18	29
IV	300	90	35	12	25	90	68	23	49
V	600	110	65	11	24	100	140	23	70

(From ref. 8)

Up to now aircraft have tended to be designed for specific flight characteristics and sprayers and spreaders have been attached. To a large extent unfavorable flow characteristics have been accepted as part of the price of playing the game and aerial applicators have avoided the most unfavorable aspects by developing operational techniques and limitations. Cut and try methods of sprayer-spreader attachment and use have resulted in a number of rules of thumb which are widely employed (e.g., limiting sprayer booms to a fraction, say 2/3 to 3/4 of wing span). It now appears to be an appropriate time to approach the problem more systematically and more scientifically.

Among the opportunities for research are:

1. Basic research on the characteristics of the flow field in the wake of the aircraft.

2. Evaluation of aircraft modifications which might alter, favorably the flow characteristics. These would include winglets, splines, turbines, tip blowing, span loading alterations, trailing edge blowing, spoilers and fences.

3. Research on chemical formulations, i.e., wet versus dry, water versus oil suspensions, additives for viscosity modification, droplet and particle size, flow rates, etc., which would behave better in the flow field.

4. Research on integrated aircraft-dispersal systems which would make optimum use of existing modified flow field characteristics.

5.10 AGRICULTURE-AIRCRAFT

A 1974 census of United States civil aircraft showed almost 6,500 ag-aircraft to be active in the United States. Of these 6,000 were fixed wing and 500 were rotary-wing. With a major exception, United States ag-aircraft and their descriptions are included among those shown in Table 5-17. The exception is the Stearman which was the Boeing PT-17 of World War II. Although long out of production about one out of every three ag-aircraft in use today is a Stearman.

Fixed-Wing Aircraft

United States ag-aircraft may conveniently be arranged into two categories: small and large. The small aircraft are in the 230 to 285 horsepower range and carry a payload of about 650 kg. These aircraft were designed for agricultural use. Probably the best known designer of this category is Weick (ref. 56) who designed the AG-I and AG-II as experimental planes. From these the Piper Pawnee was developed. A total of 2,358 Piper Pawnee PA-25's were produced between 1956 and 1973. Other small ag-aircraft are manufactured by Cessna and North American Rockwell.

The large ag-aircraft are in the 450 to 600 horsepower range and carry a payload of about 1,000 kg. In the category North American Rockwell and Wethley produce low-wing monoplanes and Grumman a biplane.

TABLE 5-17

FIXED WING AIRCRAFT

Mfg. and country	Model (wing type)	Horse-power	Gross weight (normal) Kg (lb)	Chemical load (restricted) Kg (lb)	Take-off run M (ft)	Rate of climb M/min (ft/min)	Working speed Km/hr (mi/hr)	Stall speed (flaps) Km/hr (mi/hr)
Air Parts (N.Z.)	Fletcher FU-24 (L)	300	2029 (4470)	730 (1600)	152 (500)	190 (625)	180 (112)	78 (48)
	FU-24-950 (L)	400	2358 (5200)	1044 (2300)	140 (460)	280 (920)	214 (133)	81 (50)
	Turbo-1060 (L)	500	2472 (5420)	1361 (3000)	256 (850)	290 (950)	177 (110)	88 (55)
Antanov (U.S.S.R.)	An-2M (B)	1000	5500 (12250)	1960 (4312)	200 (655)	132 (433)	200 (124)	75 (47)
Cessna (U.S.A.)	Ag Pickup (L)	230	1497 (3300)	757 (1660)	341 (1120)	121 (400)	145 (90)	92 (57)
	Ag Wagon (L)	285	1497 (3300)	757 (1660)	257 (845)	210 (690)	183 (114)	92 (57)
	Ag Truck (L)	285	1497 (3300)	1056 (2332)	207 (680)	210 (690)	182 (114)	92 (57)
	Ag Carryall (M)	285	1514 (3350)	569 (1258)	290 (885)	257 (845)	219 (135)	90 (56)
Dehavilland (Canada)	Chipmunk DHC-1 (L)	145	1100 (2420)	360 (794)	230 (750)	152 (500)	145 (90)	52 (84)
	Beaver DHC-2 MKI (H)	450	2313 (5100)	910 (2000)	170 (560)	311 (1020)	201 (125)	72 (45)
	Beaver Turbo DHC-2 MKIII (H)	578	2313 (5100)	910 (2000)	152 (500)	361 (1185)	225 (140)	97 (60)
	Otter DHC-3 (H)	600	2010 (4431)	— (—)	192 (630)	198 (650)	195 (121)	93 (58)
Emair (U.S.A.)	Paymaster MAI (B)	600	3180 (7000)	1360 (3000)	— (—)	152 (500)	185 (117)	95 (59)
Funk (U.S.A.)	F-23-B	275	1950 (4300)	680 (1500)	260 (850)	156 (515)	161 (100)	92 (57)
Grumman (U.S.A.)	AgCat (B)	450	2041 (4500)	908 (2000)	228 (750)	329 (1089)	161 (100)	107 (67)
	Super AgCat (B)	600	2041 (4500)	1133 (2500)	120 (395)	— (—)	177 (110)	— (—)
North Am. Rockwell (U.S.A.)	Aero-Comm. Sparrow A-9 (L)	235	1362 (3000)	640 (1400)	244 (800)	198 (650)	153 (95)	88 (55)
	Quail A-9B (L)	290	1663 (3600)	794 (1750)	198 (650)	260 (850)	161 (100)	88 (55)
	Snipe B-1 (L)	450	2041 (4500)	908 (2000)	183 (600)	198 (650)	161 (100)	73 (45)
	Thrush S-2R (L)	600	2722 (6000)	1133 (2500)	236 (775)	274 (900)	177 (110)	105 (66)
Pilatus (Swit.)	Porter PC-6 (H)	350	1960 (4322)	800 (1750)	130 (296)	260 (850)	187 (116)	70 (44)
Piper Aircraft (U.S.A.)	Super Cub PA18A (H)	150	949 (2090)	370 (820)	92 (300)	232 (760)	145 (90)	69 (43)
	Pawnee C PA-25 (L)	235	1315 (2900)	635 (1400)	244 (800)	192 (630)	169 (105)	98 (61)
	PA-25-L	260	1315 (2900)	635 (1400)	207 (680)	215 (705)	171 (106)	98 (61)
	Pawnee Brave PA-36 (L)	285	1970 (4400)	860 (1900)	488 (1600)	107 (350)	145 (90)	106 (66)
Wetherly (U.S.A.)	201-A (L)	450	2176 (4800)	908 (2000)	335 (1100)	292 (960)	169 (105)	111 (69)

Two planes used in Eastern-bloc countries are of interest. The Am-2 is the most widely used ag-aircraft in the Soviet Union. It was designed for multiple service: agriculture, ambulance, aerial survey, and transport. The Am-2 has a 1,000 horsepower engine and a payload capacity of 1,960 kg.

To replace the ageing Am-2 a team of Polish and Soviet engineers has developed the new M-15 which has been in production only since 1975. Some features of the M-15 are as follows:

Type:	Three seat
Wing:	Biplane wings the upper wing has slotted flaps and automatically operated slates on the leading edges. The shorter span lower wing houses the agricultural dispersal ducts.
Power Plant:	One 14.7 KN (3.306 pounds) turbofan engine mounted in a pod on top of fuselage.
Equipment:	Full flight navigation instrumentation including stall-warning indicator. The two between-wings hoppers have a combined capacity for 2,000 kg (770 gallons) of liquid or 2,000 kg (4,859 pounds) of dry chemical. The dispersal system has an agro-pump and atomizer powered by air pressure direct from the engine.

Rotary-Winged Aircraft

According to the 1974 census of United States Civil Aircraft, there were 465 piston and 38 turbine rotary-wing agricultural aircraft. The helicopter does not have the payload capacity for a given horsepower that the fixed-wing aircraft does. However, its ability to take off from and land in practically any spot large enough to clear the rotor, as well as to make shorter turns and to maneuver around rough terrain while applying chemicals, frequently makes up for low payload. The greatest deterrent to helicopter use has been high initial cost and cost of maintenance.

Engines

The supply of engines for the small ag-aircraft poses no problems. Engines in the 230-285 horsepower range are available and reliable. But engines for the larger ag-aircraft are becoming very scarce. Most large ag-aircraft manufactured in the United States use the old Pratt and Whitney R-985 or R-1340 radial piston engines. These engines have not been built since the days of World War II except for limited production in Canada in the early 1950's. They have been kept running from wartime stocks replacement parts and an engine source of 6000 BT-130 military aircraft. But they will not last forever. The following are some of the engines suggested by the manufacturer as replacements for the old Pratt and Whitney radial piston engines:

*Turboprop engines: Pratt and Whitney PT6A, 750 horsepower; Garrett TPE6, 778 horsepower; and AVCI LTP 101-600 horsepower. These turboprop engines are superior by all performance measures to radial engines but they are very expensive. Hourly and annual cost data from a Pratt and Whitney Aircraft of Canada brochure are shown in Table 5-18 and Figure 5-12

Turboprop engines have been installed in several ag-aircraft such as the Grumman Super AG-CAT, the Thrush, and the Fletcher. Harker (ref. 50) and Pratt and Whitney Aircraft of Canada (ref. 51) say that the turboprop aircraft has reduced turn time, reduced takeoff time, reduced fuel consumption, and is quieter and lighter.

TABLE 5-18

PT6 OPERATING AND OWNERSHIP COSTS
COMPARE FAVORABLY WITH RADIAL ENGINES

	PT6A-34AG	R1340
Purchase	$120,000	$28,000
Less 10% tax credit	12,000	2,800
Net cost	$108,000	$25,200
Direct Operating Costs/Hour:		
Fuel	$ 9.14	$18.56
Oil	0.38	1 80
Maintenance	1.75	1.40
Overhaul (scheduled & unscheduled)	11.80	12.77
Total hourly cost	$23.07	$34.53
Indirect Costs/Year:		
Interest on investment (9%)	$ 8,640	$ 2,016
Insurance (6%)	5,760	1,344
Total fixed cost/year	14,400	3,360
Fixed cost/hour (700 hours/year)	$20.57	$4.80
Total hourly cost	$43.64	$39.33

*Polish PZL-2S engine. This 600 horsepower, radial engine is proven in service, is rugged, and of low cost. It is still in production; but whether spare parts would be readily available and reasonably priced is not certain.

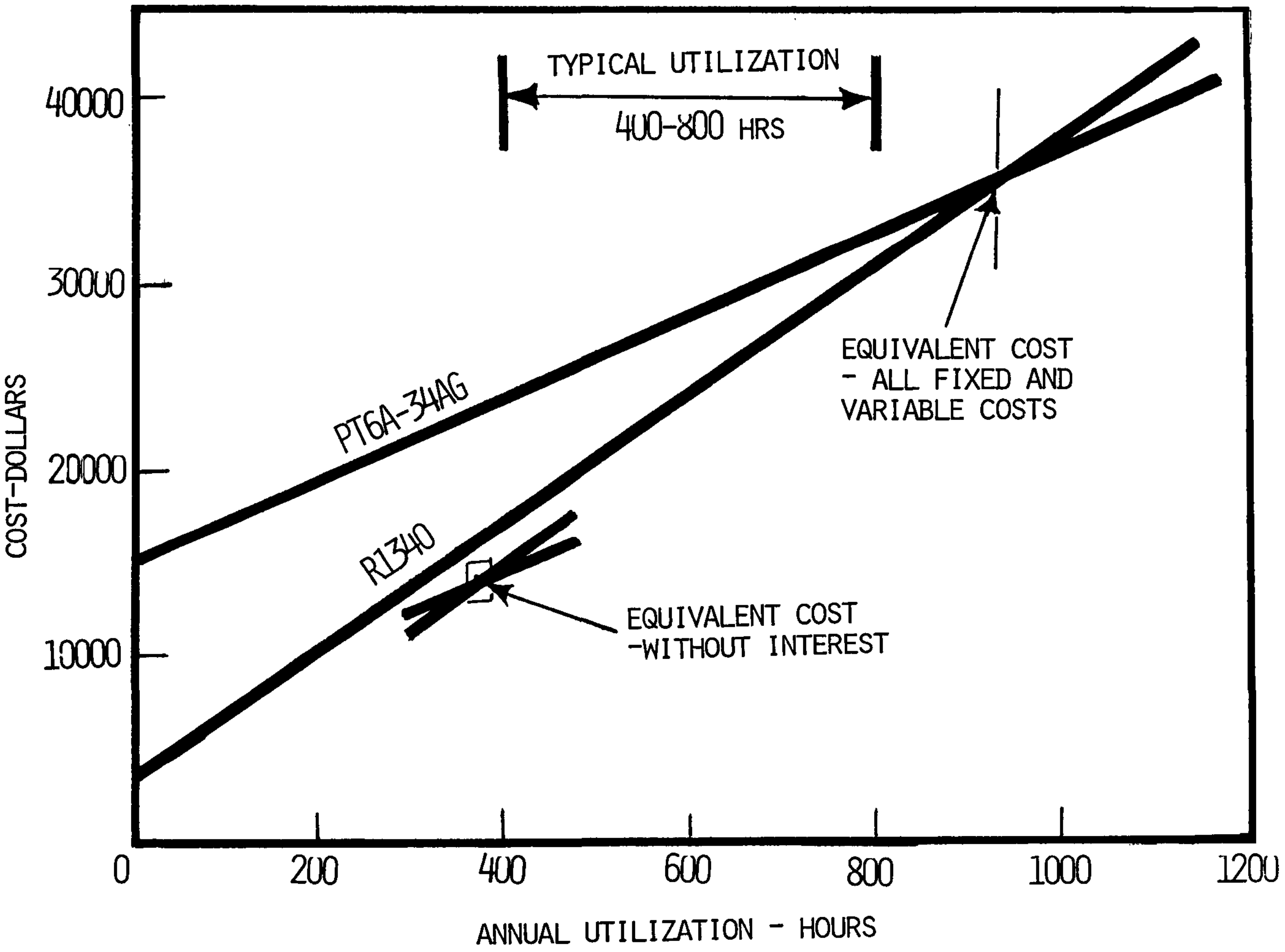


FIGURE 5-12 ANNUAL COST OWNERSHIP AND OPERATION COMPARISON
R1340 RADIAL Vs PT6A-34AG TURBOPROP

*Fred Geschwender's liquid cooled V-8 engine. This is a modified Ford V-8, iron block, fuel injection engine that develops about 425 horsepower. If it proves to function well, this engine may be a good replacement.

The accident rate of ag-air is the highest in all industrial-commerical flying. The number of accidents reported in the United States in the last three years is summarized in Table 5-19 (ref. 53).

TABLE 5-19

U.S. AG-AIRCRAFT ACCIDENTS

Year	Number of Accidents	Fatal	Serious
1976	411	34	21
1975	429	31	34
1974	438	29	54

The circumstance or causes of accidents occurring in 1976 are classified in Table 5-20.

TABLE 5-20

1976 AG-AIRCRAFT ACCIDENTS

Circumstance or Cause	Large Aircraft	Small Aircraft
Engine failure or loss of power	37%	23%
Takeoff and Landing	23%	23%
Flew into ground	14%	16%
Stall in turns	12%	10%
Collision with power lines	12%	14%
Other	2%	14%

It is clear from Table 5-20 that the major single cause of accidents is engine failure in the large aircraft. This condition stems directly from the age of the old radial engines. Other accident casues are associated with the nature of ag-air operations: frequently takeoff and landings (approximately every five minutes), flight close to ground dotted with obstacles, frequent turns with heavy loads, and pilot fatigue.

Pilot fatigue has long been considered a primary factor associated with accident rate. Pilots, performing dozens of flights in the course of one day under a variety of weather conditions, are found to be frequently under severe emotional stress before takeoff and during flight (ref. 54). A survey (ref. 55) of 24 pilots engaged in aerial application indicated the following: (a) generally the group lost weight; (b) body temperature rose as high as 38.5°C (101.3°F) during flight; (c) blood sugar in eosiniphil cells tended to decrease during the work period indicating fatigue and (d) pilots lost sleep due to irregular hours.

There appears to be no question that agricultural flying is an extremely hazardous occupation. It is thus essential that every consideration be given to reducing hazard and fatigue by providing the best possible equipment specifically designed to those ends.

Effects of toxic chemicals must also be considered. Pilots, flagmen, and ground crews may be adversely affectly in the absence of adequate procedures and protection.

Desirable Ag-Aircraft Characteristics

The following are desirably characteristics of ag-aircraft:

A. High productivity and economical effectiveness:

1. low empty weight and high payload
2. high-speed cruise and low-speed delivery
3. high life, low drag wings
4. short takeoff and landing capability
5. low capital cost
6. multi-purpose capability

B. Airframe Structure

The airframe should be rugged, sturdy, and fatigue and corrosion resistant. Landing gear should be well designed for hard landings.

C. Safety

1. controlled environment in cockpit.
2. maneuverable, responsive, simple and easy to handle
3. safe and effective chemical loading
4. complete navigational equipment, stall warning and guidance system

5. hopper and attached tanks positioned in front of the pilot

6. cockpit which will stay intact after impact

7. an emergency release of the entire load within five seconds

D. The Engine

1. powerful, simple, and lightweight

2. in production with available spare parts

3. capable of powering agro-pumps and atomizers

4. minimum maintenance and overhaul requirements

5. dependable and rugged

6. low specific fuel consumption

E. Pilot Physical Comfort

1. well designed seat

2. controlled environment in cockpit

3. controls easy to handle

4. windscreen easy to clean

5. good visibility

Proposed Research in Aircraft and Propulsion Technology

Many agricultural aircraft and all ag-aircraft engines were designed for other purposes and then modified or adapted to agricultural use. Many of the engines, particularly those in the 400-1,000 horsepower range are military surplus from World War II and have not been in production for years. Even new aircraft built specifically for agricultural use are based upon design concepts decades old. Because of the huge investment in equipment by a large number of operators and because of the diversity of the market we may expect existing equipment to continue in service for many years. This equipment will also continue to be adapted and modified to meet whatever the need for an evolving ag-air market; nevertheless, the time is approaching for the design and production concepts which recognize changed conditions in the aerial applications field.

New Engine Design

Simply the fact that the supply of engines from the surplus market is drying up and existing engines, except for the small ag-aircraft, are wearing out demands a new line of aircraft engines. A series of engines in the

400-1,000 horsepower range would find a ready market in the replacement field; they would also trigger the design of new aircraft. It is obvious that any new engine should be lightweight, and economical to run and maintain. Ag-air maintenance in the field and a provision for substantial power takeoff to run dispersal equipment are highly desirable features.

Among the opportunities for research and technology are:

1. Research on optimum size, weight, power, power takeoff ratio, etc.

2. Research on configuration: turbine versus piston engine, air cooled versus water cooled, direct drive versus geared, etc.

3. Research on economy such as first cost and maintenance costs and environmental consideration such as pollutants and noise.

Aircraft Design

Aircraft in use today use aeronautical technology developed in the 1940's and 1950's. While these aircraft served the market needs of the past, there is less assurance that they will meet the needs of the future. If nothing else the status of the aging engine in the ag-air fleet will alter the future of ag-air. So will the changing market resulting from changes in farm and field size, crop choices, chemicals, equipment costs, etc.

With the need for a new series of ag-air engines so clearly established, we should expect a new series of engine designs. A new engine design should be accompanied by new aircraft design which have high compatability with the engines and which use aircraft design and production concepts developed in the thirty years since the last agricultural aircraft was designed.

Ag-air operates in a demanding environment under conditions which are probably more critical than those of any other commercial operations. They carry out normal operations at extremely low altitude, performing a number of maximum rate turns during every flight. In order to reduce turn-around time at the end of each swath, they operate near the stall speed for an appreciable period of time. Leading edge slats, slots and flaps have the potential for providing all the above benefits. Their use can result in a large increase in stall speed. At the same time, the angle of attack is raised well above that at which theplain wing would ordinarily stall. Thus slats, slots and flaps appear to offer a combination of features which are uniquely adopted to agricultural operations.

Among the opportunities for research and technology are:

1. Research on aircraft configurations: high or low wing (or both), turbine or piston engine, engine-aircraft compatability, etc.

2. Research to improve aircraft wake characteristics for ag-air needs.

3. Research on payload performance: payload range, minimum empty/gross weight ratio, structural design, dispersal system - aircraft integration.

4. Research on slats, slots and flaps.

5. Research on safety: crashworthiness, cockpit design, control systems, etc.

6. Research on guidance and control.

7. Research on pilot fatigue: physical and psychological.

8. Research on propeller noise pollution.

9. Research on safe and effective chemical loading, carrying and dispersal system.

10. Research on cockpit controls and environment for safety and comfort.

5.11 GUIDANCE AND CONTROL SYSTEMS

The Positioning Problem

A basic problem in agricultural aviation is the achievement of uniform distribution of aerially-applied materials at a prescribed coverage density. The materials (insecticides, herbicides, fertilizers, seeds, etc) are generally applied by dispersal from an aircraft flying in successive straight or curvilinear paths, separated by a fixed distance. An error in judging the "fixed" distance may result in incorrect distribution of the material along any particular pass. The incorrect distribution may be too sparse to be effective, or so dense (in the cast of pesticides and herbicides) that the valued crop is injured.

A non-uniform distribution on the ground may be the result of incorrect swath spacing, a poor ejection density pattern, or non-parallel flight paths. The first of these may be due to navigational error, and the latter two may be due to problems with the dispersal system or to cross-winds. Only navigational errors will be discussed here. Other problems are discussed elsewhere in this report.

In the following analysis, the problem of attaining the correct average density of material on the ground is examined. Suggestions are made for automatically controlling the aircraft's motion and material ejection rate in an attempt to achieve the correct average density. In Figure 5-13 two assumed dispersal patterns are shown, one trapezodial and the other triangular. In each case the horizontal dimension is caled distance and the vertical dimension is relative density of dispersed material reaching the ground for each swath. Absolute lateral symmetry of the aircraft's wake (fictitious, of course), ideal ejector placement, and zero or constant velocity cross-winds are assumed. Constant vertical displacement and groundspeed are also assumed. These patterns are commonly used by agricultural aviation operators in calculating swath

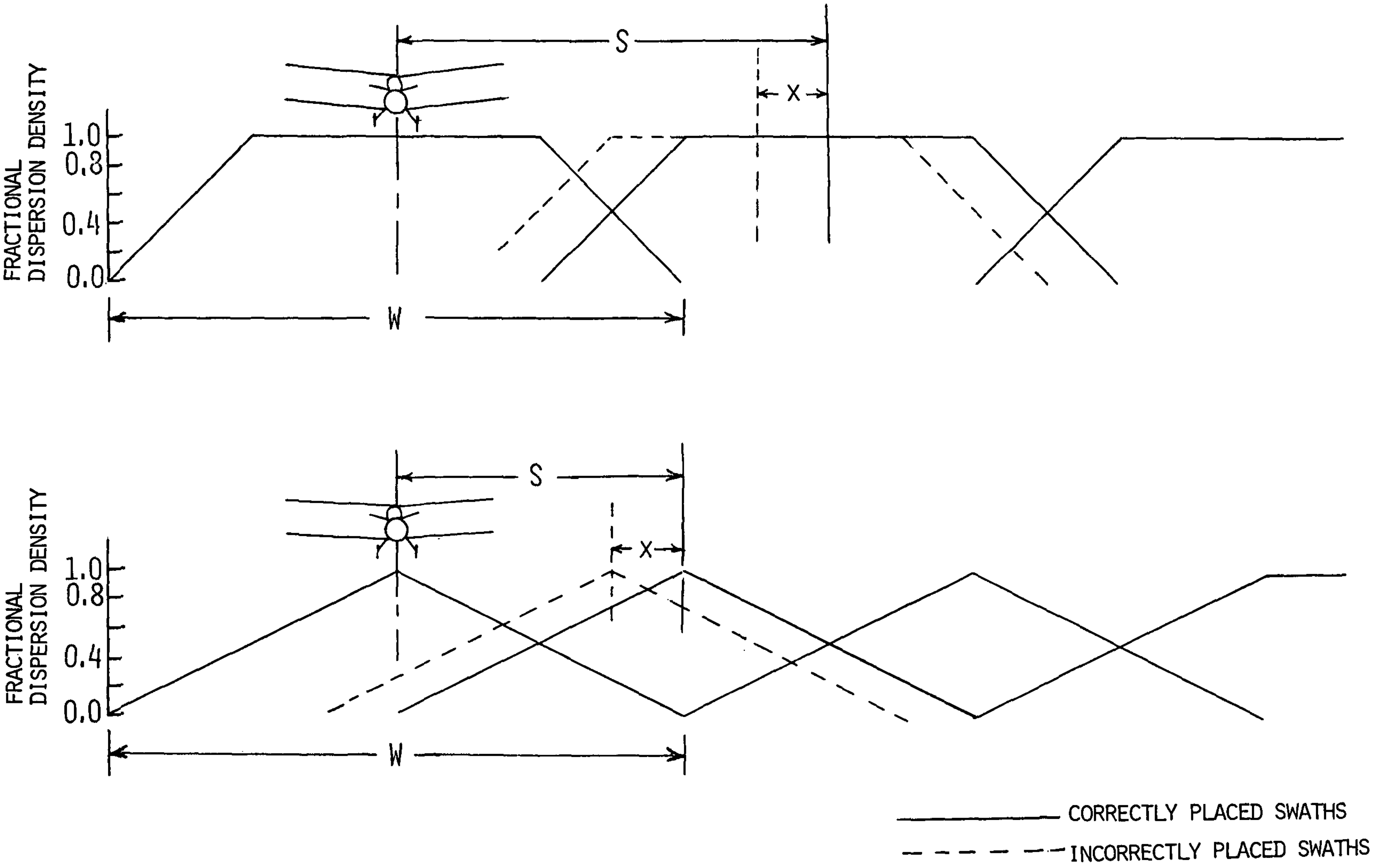


FIGURE 5-13 SWATH WIDTH, W, SWATH SPACING, S, AND SWATH SPACING ABSOLUTE ERROR, X

spacings (ref. 20). For both patterns, W is the swath width, S the ideal, or correct, swath spacing for a desired average density, and x is the error in swath spacing. If the swath spacing error is normalized by dividing by S, then the single variable $\varepsilon = x/s$, the relative swath spacing error, can be used to calculate density errors for either dispersal pattern. A negative value of ε denotes swaths too close together, while positive ε signifies swaths too far apart.

The error is achieved average density is expressed as:

$$E = \frac{1}{1 + \varepsilon}$$

where E is the ratio of achieved average density to desired average density.

Figure 5-14 is a graph of E vs. ε, and applies equally to both dispersal patterns given in Figure 5-13. With no positioning error ($\varepsilon = 0$) the correct average density is attained ($E = 1$).

The above equation may be inverted and differentiated to allow estimation of the horizontal positioning accuracy required for any allowed error in average achieved density:

$$\varepsilon = \frac{1}{E} - 1$$

$$\frac{\Delta\varepsilon}{\Delta E} \simeq \frac{\partial\varepsilon}{\partial E} = \frac{-1}{E^2}$$

$$\Delta\varepsilon = \frac{-\Delta E}{E^2}$$

$$\simeq -\Delta E \text{ for } E \simeq 1.$$

Thus, in order to achieve an average density within ten percent of the desired average density, a relative positioning error of no more than a tenth of a true swath spacing (regardless of the swath width) can be tolerated. This, of course, assumes an ideal trapezoidal or triangular dispersal pattern, with zero difference in ground speed between opposing directions of flight. Also, those calculations address only the average density over the interior of the field. Density close to the edges of the field, and striping (alternate bands of varying density) are not considered here.

Note the navigational advantage obtained when the dispersal rig is arranged to give a trapezoidal pattern rather than a triangular one: for a given tolerance in achieved density, ε is the same for either pattern. However, since $x = \varepsilon S$, and S is larger for the trapezoid than for the triangle, then x, the absolute error in swath position, may be larger. (This is reasonable, in view of the large control area over which the density is uniform). A typical value for W (either pattern) is 30 meters. S for the triangular pattern would then be 15 meters, and that for the trapezoidal pattern might be about 22 meters.

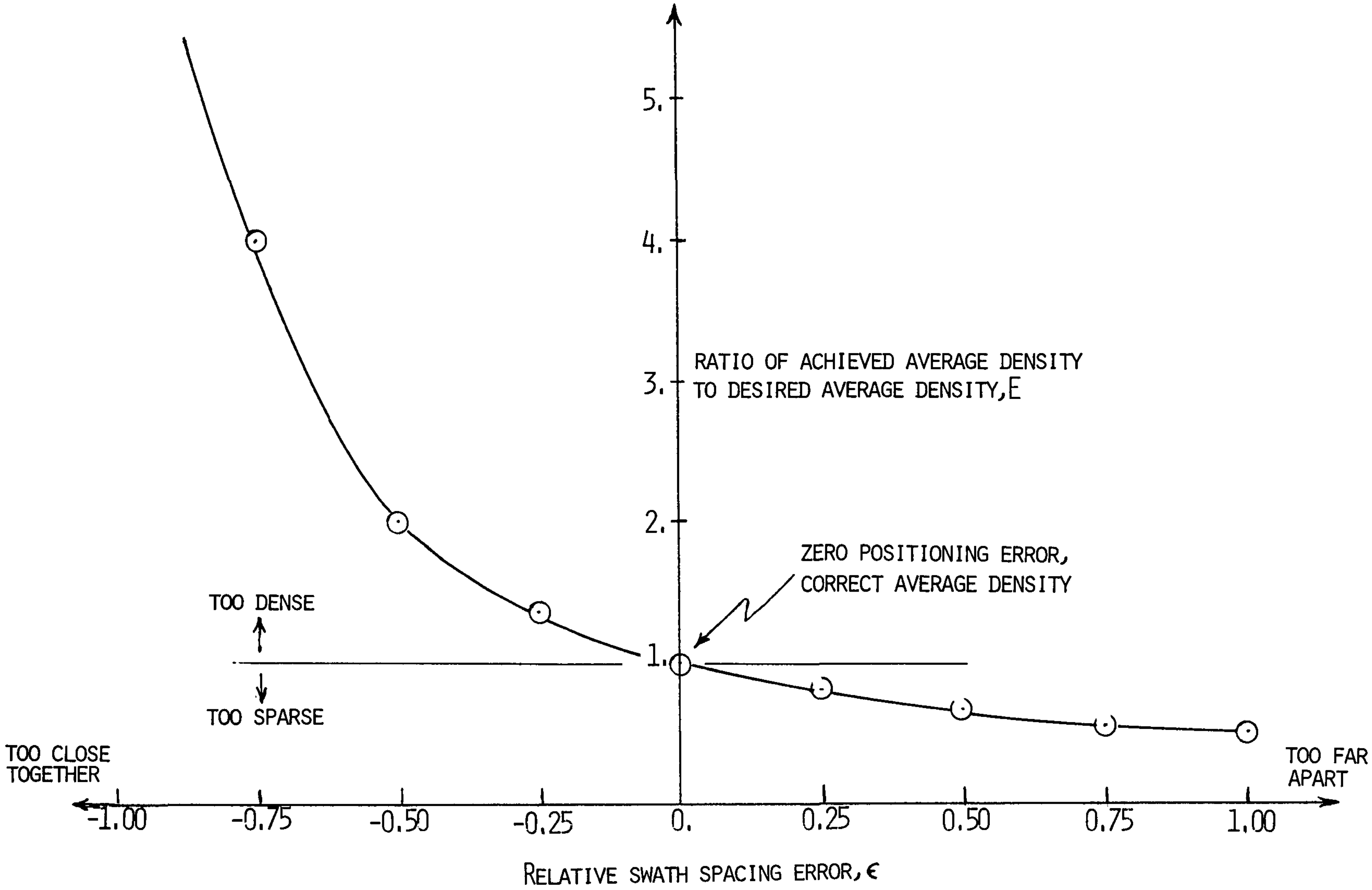


FIGURE 5-14 ACHIEVED DENSITY AS A FUNCTION OF SWATH POSITION ERROR

To have no more than ten percent error in average density, a pilot using a triangular rig must align his swaths with an accuracy of 1.5 meters. However, if his rig is trapezoidal, he can afford to be about fifty percent less accurate (with the trapezoidal geometry specified here). This relaxes the requires accuracy to 2.2 meters.

To maintain correct spacing between successive passes over a field, pilots have employed various schemes to provide visual markers at one or both ends of the field (as well as along thepath, in the case of very large fields). The visual markers in some cases are natural features such as trees. In other cases a marker or set of markers is moved in a direction perpendicular to that of the aircraft's passes; this is the traditional "flagman," or "chaining" approach. On certain frequently-treated fields, permanent flags or markers are installed, and it is up to the pilot to keep count of the markers he has flown over.

Recent developments in flagging have included temporary markers launched downward from the aircraft at the beginning and/or end of each pass. Among these markers are smoke bombs, paint spots, and streamers of toilet paper (ref. 20 & 65). Use of these devices requires the pilot to accurately judge lights laid across one end of the field, with each light switched on by a radio transmitter on board the aircraft, and then switched off, presumably, by a timed-delay switch. Each light stays on long enough for the pilot to complete one pass (ref. 66).

There have been many problems in the use of live flagmen, since a flagman is frequently sprayed with the dispersed material, which in many cases is toxic. This exposure leads to high costs for medical checkups and insurance, and requires that individual flagmen be rotated frequently in order to reduce each man's exposure. Another problem inherent in the use of flagmen is that, being bound by truck and road, they take more time to get from field to field than the aircraft does, which results in lost time for the pilot.

Electronic navigation systems such as those in use for long aircraft flights or for marine positioning have found only limited use in agriculture. Aside from initial cost factors, this is due to the high frequency of turns which must be made by the agricultural pilot, and the lack of time available for him to respond to the information provided by navigational aids. Over very large areas such as forests, however, electronic navigation systems such as the Decca Hi-Fix have been used. In order to achieve the required accuracies, the ground transmitters are set up at right angles to the intended passes, and an onboard computer keeps count of the aircraft's distance from each transmitter and reduces this information to a simple "go left" or "go right" display easily followed by the pilot. Accuracies of two to three meters are reported (ref. 20, p. 148).

Once the electronic navigation equipment is installed in the ground and aboard the aircraft, the navigational data may be displayed either as the "left-right" indication (usually a meter needle to be kept centered), or as a moving-map display. Moving-maps give a continuous plot of position and are generated by electronic transformation of the navigation arcs into rectangular coordinates used to move a marking pen over a paper map of the target area. Such display systems have been used successfully by air-sea rescue units and by airline companies. Plotting resolution is at any convenient scale, and a permanent flight path record (useful to the agricultural pilot in establishing compliance with his contract) is provided (ref. 67).

The Speed Problem

The effect of errors in ground speed is expressed quite simply: for a given material ejection rate, too great a ground speed will (to a first approximation) cause too sparse a density of material on the ground. Secondary effects such as modified vortex patterns and different ejection patterns at the greater speed, keep this simple relationship from being linear. However, if these effects are neglected, then the simple expression

$$E = \frac{V_0}{V}$$

may be written, where E again is the ratio of achieved to desired average density, V_0 is the correct groundspeed, and V is the actual groundspeed. Thus, for a given material dispersal rate (per unit time) a constant density (per unit area or distance) requires a constant groundspeed. And attainment of a given density requires that the groundspeed be maintained at a specific value. From the above expression,

$$\frac{\Delta V}{V_0} = \frac{-\Delta E}{E^2}$$

$$\simeq -\Delta E \text{ for } E \simeq 1,$$

where ΔV is the error allowed in ground speed for a given error in average density.

The pilot wishes to fly antiparallel swaths at constant groundspeed (to achieve a uniform dispersal rate) and a constant airspeed (to avoid excessive throttling).

The aircraft's velocity with respect to the ground is $\vec{V}$ (the vector whose magnitude is V above) which is the vector sum of the aircraft's velocity $\vec{C}$ with respect to the wind, and $\vec{U}$, the wind velocity:

$$\vec{V} = \vec{C} + \vec{U}$$

If the ground velocity in one direction is called $\vec{V}_1$ and that in the other direction $\vec{V}_2$, and if the velocities with respect to the wind are designated in a similar manner, then:

$$\vec{V}_1 = \vec{C}_1 + \vec{U} \qquad (100)$$

$$\vec{V}_2 = \vec{C}_2 + U \qquad (101)$$

To maintain a constant ground speed (scalar) in opposite directions, the pilot wishes to achieve ground velocities such that:

$$\vec{V}_1 + \vec{V}_2 = 0. \tag{102}$$

Also, in order to maintain a constant airspeed (also scalar), the pilot desires that:

$$C_1 = |\vec{C}_2| = C_2 = |\vec{C}_2|. \tag{103}$$

Equation (102) places a vector constraint and equation (103) a scalar constraint on the pilot's choice of speed and direction with respect to the wind. From (100), (101), and (102),

$$0 = \vec{V}_1 + \vec{V}_2 = (\vec{C}_1 + \vec{U}) + (\vec{C}_2 + \vec{U})$$

$$= \vec{C}_1 + \vec{C}_2 + 2\vec{U},$$

$$\vec{C}_2 = 2\vec{U} - \vec{C}_1$$

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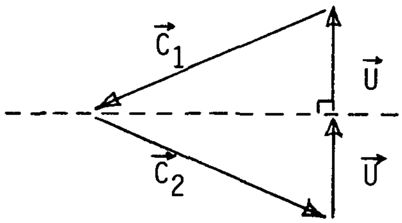
$$= -(2\vec{U} + \vec{C}_1) \tag{104}$$

A vector diagram of the solution expressed by (104), which also satisfies (103) is:



This means that the pilot should fly so that his ground velocity vector is perpendicular to the wind. For wind speeds considerably less than that of the aircraft, this means that the aircraft should fly cross-wind. Indeed this is a very popular mode among agricultural pilots, although for a different reason: if a pilot flies cross wind swaths, making each swath upwind of the previous one, he will not have to fly through any material he has previously dispersed. Enclosed cockpits will lessen this requirement. However, until airspeed or dispersal rate is automatically controlled, the navigational advantage will remain.

Flying cross wind does, however, increase the possibility of lateral drift of the dispersed material, and also skews or otherwise distorts the dispersal density pattern. Other modes are in use, but these require swath-to-swath speed compensation, often requiring the pilot to fly at some speed other than the safe design speed of the aircraft, or requiring that uniform dispersal be forfeited.

If the wind is not fairly calm and steady, or if the pilot is unable to maintain a constant swath-to-swath groundspeed, then compensation would ideally be made by varying the rate of flow of material from the aircraft's ejecting device.

Presently, nozzle orifice size or spin rate is set before take off, and this remains fixed for the duration of the flight. The pilot may, of course, interrupt the flow for periods when he is not executing passes over the field to be treated. To achieve a different flow rate, the outlets must be adjusted or replaced on the ground. This is a time-consuming process, usually requiring about 25 minutes for a typical airplane or helicopter dispersal rig. Choice of nozzle size, configuration or atomizer spin rate, requires predetermined information relating groundspeed to flow rate. Some innovative spray systems allow variation of the orifice size or delivery pressure in flight, but proper use of these also assumes certain relationships between time rate of flow from the opening and spatial uniformity of the material arriving on the ground or on the crop. These relationships are always empirically or theoretically estimated or are based on experiments conducted under conditions other than those experienced on the actual field.

Positioning and Dispersion as a Combined Problem

The previous solutions are attempts to solve the problem of uniform distribution by choosing a dispersal flow rate and then monitoring and guiding the progress of the aircraft's position over the treated field without regard to the material density actually achieved. A far more satisfactory approach to this problem would be a closed-loop one, in which the knowledge of the material density on the ground is used to control the speed or position of the aircraft and/or the nozzle or ejector flow rates, as suggested in Figure 5-15.

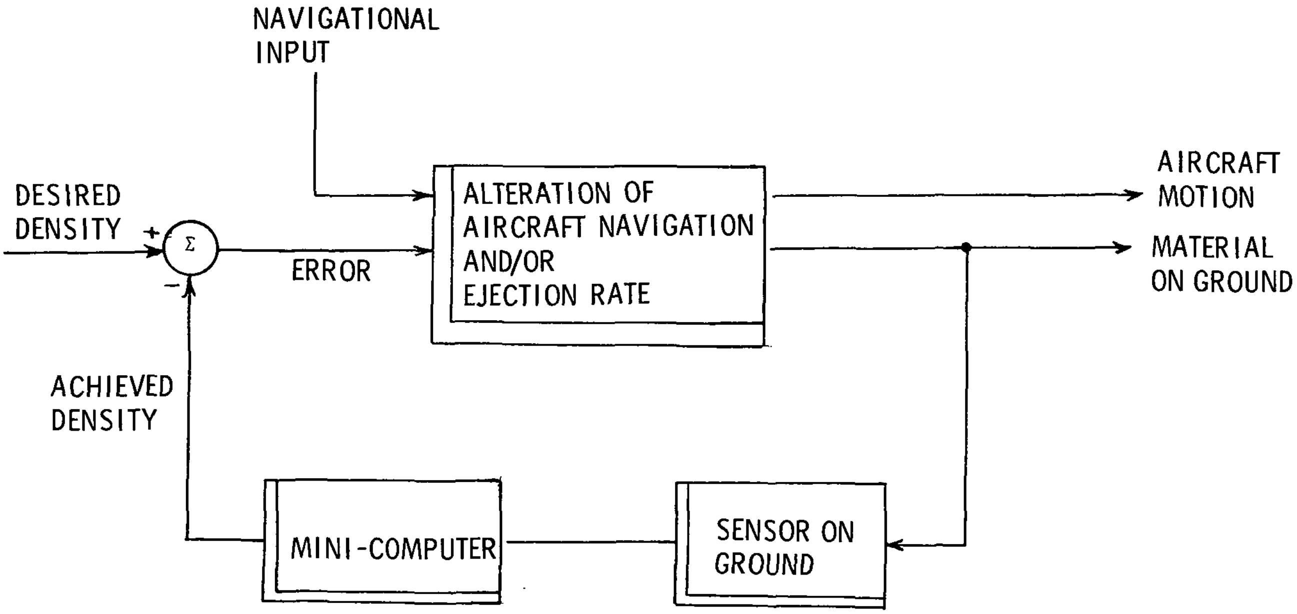


FIGURE 5-15 CLOSED-LOOP SYSTEM FOR ACHIEVING A GIVEN DENSITY OF DISPERSED MATERIAL

This approach would, of course, require sophisticated sensing devices and servomechanical controllers in order to coordinate the aircraft's flight parameters and the time rate of dispersal with the measured spatial rate of dispersal. Except for solving certain time-delay problems, the technology and hardware to provide such a system is presently available. The initial purchase and installation cost to an individual agricultural aviation operator may be prohibitively high. However, if the mini-computer industry continues its trend of developing and supplying more compact and more powerful computing and interfacing equipment for lower prices, then this closed-loop approach to the dispersal problem becomes a reality.

If the problem of distributing materials uniformly onto a treated field is divided into the separate problems of navigation and variable temporal rate or dispersal, then several immediate solutions are suggested. Several companies presently market microwave positioning systems specifically designed for accuracies of one meter over a five kilometer distance. A typical system consists of three small transceivers and one distance-measuring processor unit, with one of the transceivers and possibly the processor unit (total weight of both units is 15 kg) installed in the aircraft (ref. 68). Such units are used regularly by hydrographers in bathymetric surveys, and the update rates can be made high enough (up to ten per second) to be useful to the pilot of a fast moving aircraft. The "left-right" display presently used by marine helmsmen to steer a prescribed line would be easily useable aboard a frequently-turning aircraft. Going a step further, the signal which is fed to the "left-right" display could be used as the error signal for a servomechanism which controls the rudder or other control surfaces in order to keep the aircraft on the line automatically.

On-board electronic navigation systems could also be used to accomplish two other functions of great interest to agricultural pilots; automatic turns and obstacle avoidance. At the end of each line the navigation system could calculate the electronic coordinates of the next parallel line to be flown, and, in conjunction with other flight parameters, automatically turn the aircraft and bring it onto the next line. The problem of obstacle avoidance occurs in the case of fast military aircraft flying at tree-top level, and the solutions should find application in helping slower agricultural aircraft to avoid trees or electrical wires.

Given that the pilot is in the correct position, or steering the correct heading along the proper path, and that he knows it, he must still have some control over the rate of flow of materials from the dispersal rig on his aircraft. If this rate is not controlled by devices which sense the achieved distribution, then the pilot should be able to adjust his flow rate rather than be forced to alter his airspeed. If he can adjust the flow rate, then he will be free to vary his airspeed in accordance with safety considerations. The adjustment of the flow rate could even be made by a small controller system which senses air or ground speed, thereby allowing the pilot to concentrate on flying the aircraft. He would be free to choose his swath direction without being constrained to flying at right angles to the wind.

One way to increase the safety of an agricultural pilot is to keep him on the ground while his aircraft goes aloft. To get from today's sophisticated radio-controlled model airplanes and helicopters to a remotely-piloted agricultural aircraft is primarily a question of scale; the telemetry and the control mechanisms are already available. Also, full-sized drone aircraft have been in use for years as military targets and certain weapons systems utilize terrain-following guidance schemes. The problem of remotely piloting a low-speed aircraft over an open agricultural field must surely be less complicated (and therefore require much less expensive solutions) than the military remote guidance problems already solved.

Airborne Interception of Pests

Rainey (ref. 69) has described the successful inflight detection, tracking, and interception of locust swarms over the Sudan, using aircraft equipped with droppler radar. These insects, once intercepted, are then attacked by ultra-low-volume (ULV) insecticide from the aircraft, or are collected to provide data for statistical population studies. These operations call for extensive use of guidance and positioning systems, and the technology could be used to detect materials other than insects. For instance, a ground-based or airborne droppler radar could be used to track the movements of a mass of agricultural material which is drifting in the air due to improper aerial application.

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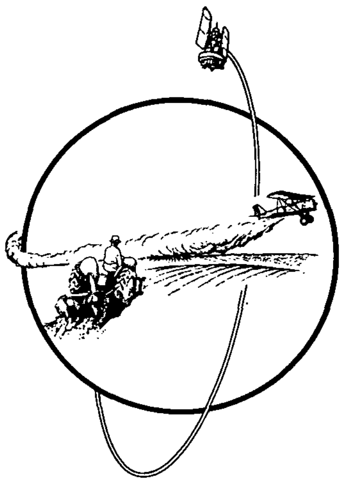

Remote Sensing

"TRAVELING THROUGH HYPERSPACE ISN'T LIKE DUSTING CROPS, BOY!"

— HAN SOLO, REF. 37

CHAPTER 6

REMOTE SENSING

A significant role of aerospace in agriculture is the remote sensing of earth resources. This chapter examines types of remote sensing systems currently in use and under investigation, management and technology of systems, nature of weather and climate forecasting and modification with particular application to agriculture, and economics and benefits of remote sensing system.

6.1 REMOTE SENSING SYSTEMS

The following sections consist of discussions of resolution and scale, aircraft and spacecraft and their concomitant sensor packages, and specific applications of remote sensing to agriculture.

Resolution and Scale

Consider a hypothetical neophyte viewing a remote sensing image. Call him Elmudo de Remoto Sensore (the world of remote sensing). Elmundo exclaims, "I want to be able to see my barn and at the same time the world too!" This seems to be a most unreasonable request if Elmundo wants both scales of information, his barn and the world, on the same image. Technologically, remote sensing can provide many useful forms of information but not always at the same time, from the same sensor, and at the same map scale. For Example, high resolution imagery from 3,000 meters (10,000 feet) could show Elmundo's barn, his corral, even cattle in the corral. But, it cannot give us global coverage in a usable form even if the entire earth were photographed from an altitude of 3,000 meters and joined into a single image. The task of piecing together such a mosaic would be staggering enough, let alone the difficulty of trying to view the entire earth from 3,000 meters. Global coverage, however, can be achieved with remote sensing from satellites. Hemispheric views of the earth from space are regularly being imaged and transmitted from meteorological satellites (ATS, SMS, and GOES) at a geosynchronous altitude of 36,000 km (19,400 nm) (ref. 1, pp 567-586).

The question which underlies nearly every initial discussion in remote sensing from space is: What is the resolution? Is "resolution" really as important as the neophyte thinks it is? Resolution is relative. It depends on the resolving power of the sensor (lens) and on the altitude or distance above the ground. Resolution refers to the capability of the interpreter to distinguish between paris of lines set a small distance apart. Elmundo's problem is that he expects too much from one system. He wants to see fine, familiar details while at the same time viewing images of the earth taken from an unfamiliar distance.

FIGURE 6-1 MEDIUM ALTITUDE JET AIRCRAFT

Unlike the biological sciences which view parts of the earth's vegetation at a microscopic scale down to the cell level or smaller, the users of remote sensing view the earth's surface from afar to obtain information at a vastly different scale. "He couldn't see the forest for the trees" applied to this simple concept of difference in scale.

Remote Sensing Systems: Aircraft

Almost any airplane can be used as a remote sensing platform. Conventional aircraft vary from small single-engine propeller-driven planes to jet military aircraft. Aircraft platforms for remote sensing of agriculture can be conveniently divided into three classes: high-, medium-, and low-altitude.

Present U.S. high-altitude remote sensing missions are being performed by U-2 aircraft currently being maintained at NASA's Ames Research Center, California. The U-2 at altitudes of 21,300 m (70,000 feet) provides wide aerial coverage with its aerial mapping cameras with extremely good resolution of 3 to 8 meters (ref. 1, p 561-562). The best of both remote sensing worlds are available - high resolution and braod aerial coverage.

Even with its range of 4,299 km (2,600 miles) the U-2 is limited. Because of its unique detachable landing gear, the U-2 can be serviced at and flown from only two NASA airport facilities - the home base at NASA-Ames Research Center in California and at NASA's Wallops Island facility in Virginia. As a consequence, large aerial coverage of the U.S. has been limited to regions along the east coast and westward to the Mississippi Valley and along the west coast with inland coverage to Arizona. Ironically, the interior U.S., where the majority of our wheat and corn acreages are located, has very little U-2 coverage. Another limitation is the cost of conducting regular surveys with high-altitude aircraft. The cost comparisions discussed below show high-altitude aircraft to be the most expensive remote sensing platform.

Medium-altitude aircraft are used at altitudes of 9,000 to 15,000 meters (29,500 to 49,200 feet). Private business jet aircraft have been used for most of the remote sensing activities at this level. With special sensor pod configurations, such aircraft can carry an array of multispectral cameras, aerial mapping cameras, and a thermal infrared scanner. Because of their high altitude service ceiling of 13,700 meters (45,000 feet) and their range of 2,400 km (1,500 miles) or more at speeds of 805 km/hr (500 mph), such aircraft approximate the capability of the RB-57 and U-2 aircraft without having the unique operational limitations and cost of the high altitude systems. Furthermore medium altitude business-type jet aircraft are more readily available for purchase and operation, unlike the RB-57 and U-2 "government" aircraft (ref. 1, pp 553-555). Despite their popularity and availability, business jets are expensive to purchase and operate. Unless they are needed for large area coverage (i.e., statewide or regionwide) for high altitude 1:80,000 map scales, such aircraft are of limited effectiveness.

Table 6-1

PHOTOGRAPHIC REMOTE SENSING SYSTEMS

SENSOR(S)	FOCAL LENGTH	FILM FORMAT	FILM/FILTER COMBINATIONS	USE
HASSELBLAD 500 EL CAMERAS	80-100 MM	70 MM	1-7	Multispectral with 2 to 4 cameras
I^2S MARK I AND SPECTRAL DATA MODEL II MULTISPECTRAL CAMERAS	150 MM	8.9 X 8.9 CM	1-4	Multispectral 4 lens cameras
WILD HEERBRUGG RC 10	150 MM	23 X 23 CM	1-7	High resolution, mapping camera but only one film/ filter combination per mission
FAIRCHILD KC-6A	150 MM	23 X 23 CM	1-7	High resolution, mapping camera but only one film/ filter combination per mission
ZEISS RMK A 15123	150 MM	23 X 23 CM	1-7	High resolution, mapping camera but only one film/ filter combination per mission

Film/Filter Combinations

1. Panchromatic black and white/wratten 47-Blue
2. Panchromatic black and white/wratten 57A-Green
3. Panchromatic black and white/wratten 25-Red
4. Black and white infrared/wratten 89B-Deep Red
5. Normal color/ultraviolet-Clear
6. Color infrared/wratten 15-Yellow
7. Water penetration film/wratten 2-4-Yellow

Low-altitude aircraft range from single engine piston turbo-powered conventional aircraft to multi-engine aircraft. Maximum service ceilings can extend to 9 km (29,500 feet) but most low-altitude remote sensing activities are carried out under 3 km (10,000 feet). With airspeeds of 280 km to 360 km (175 mph to 225 mph) most low-altitude aircraft are limited to ranges of 970 km to 1900 km (600 to 1,190 miles) (ref. 1, pp 550-552). Such range limitations place them into a local-use category for which remote sensing applications are aimed at county or, at most, small regional level.

Sensors in current use on remote sensing aircraft for agricultural applications involve a variety of multispectral cameras with different film-filter combinations and aerial mapping cameras. Within the electromagnetic spectrum (EMS), experimental sensing of crops range from the ultraviolet regions to microwave regions (radar). However, in practice, most remote sensing activity is concentrated in the visible and near-infrared portions of the EMS through use of cameras and films (ref. 2). Table 6-1 contains a list of selected cameras, films, filters, and combinations used in aircraft remote sensing of agriculture.

Global Inventory of Agricultural and Earth Resources: The Case for Landsat

Limits to photographing large areas by aircraft are well known. NASA's U-2 aircraft, our best high altitude aircraft platform, is limited to five hours flying time at 21,300 meters (70,000 feet) over a range of 4,200 km (2,600 miles). To conduct a global inventory requires an orbiting space system which can image the entire earth at scales which permit the most important resource boundaries to be discerned at or near 100 meters (ref. 3). It must be a system which can produce the inventory, at least image the earth, in a relatively short period of time, so that comparisons between areas can be made as a measure of spatial variation and not temporal variation. At the same time, it must be a system with regular repeatability to measure temporal variations within given localities. That system is currently Landsat.

The capabilities of the Landsat System (Landsat I and II) which make it particularly valuable for making an inventory of agricultural and other earth resources include:

1. Polar Orbit. Landsat I and II, traveling in tandem nine days apart, orbit every 104 minutes as the earth turns beneath them.

2. Sun-Synchronous. The orbits are adjusted to synchronize with the sun so that in the descending mode (N-S) the satellite always senses a given location at the same local sun time. This timing provides an angle of illumination which remains relatively constant, varying only with the seasons. The advantage here is that tone values or spectral brightness values are comparable along parallel latitudes globally.

3. Repetitive Cyclic. Any given point on the earth's surface, except in the extreme polar areas, can be imaged every 18 days by each satellite. As the satellites are in tandem 9 days apart, any given

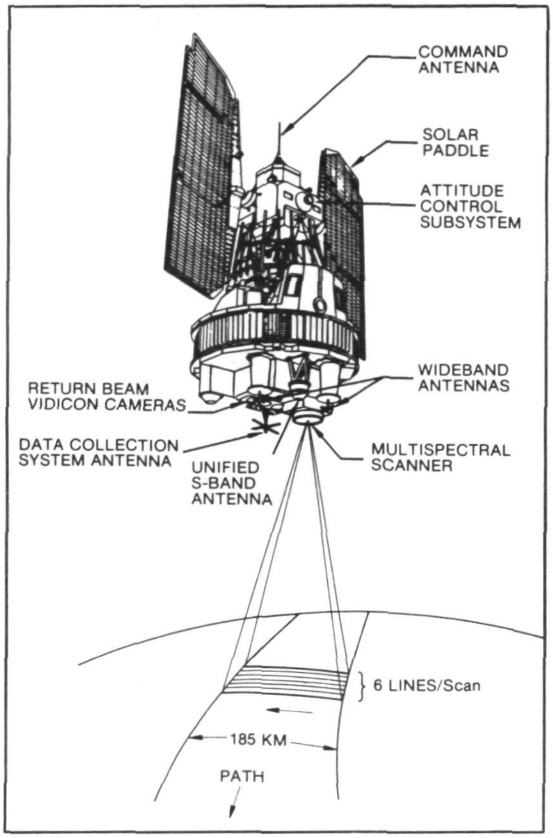

FIGURE 6-2 LANDSAT

area can be imaged every 9 days. Theoretically this provides 40 different observations per year for a particular site. In a practical sense, however, two limitations exist with the present Landsat System:

a. Not all areas of the earth are being imaged

b. Cloud cover prevents 40 cloud-free observations for most areas under investigation.

The repetitive, cyclic coverage, however, provides the essential capability of monitoring crop conditions, rates of growth, disease and pest diffusion, and the potential monitoring of the effectiveness of pest and disease eradication.

4. Multispectral. The multispectral scanner sensors on Landsat are sensitive to visible light and near-infrared radiation coming from the earth's surface. Designated as spectral bands 4, 5, 6, and 7, the multispectral regions covered are: band 4 representing blue-green light and .5 to .6 μm; band 5 representing red light at .6 to .7 μm, and bands 6 and 7 representing near infrared radiation at .7 to .8 μ and .8 to 1.1 μm respectively. Imagery for each spectral band is available in black and white photographs. Color composite imagery (color infrared) is composed of bands 4, 5, and 7 projected in combination onto color film to render color infrared imagery (ref. 4)

The most useful single band imagery for agricultural applications is band 5, which senses red light information. In this part of the spectrum, vegetation patterns are contrasted with bare earth surfaces so that forests and farmland (crops and pastures) can be distinguished from bare earth and urban-build-up areas. Color composite imagery (color infrared) is best for overall agricultural purposes. Image signatures for crop types and their stage of growth and vigor, albeit still in a crop signature stage of experimentation, indicate a reasonable utility of imagery for agricultural inventory and monitoring.

Sensing Constraints for Aircraft and Landsat Systems

Remote sensing of agriculture for crop identification, disease and pest detection, and yield estimation is constrained by the following variables:

1. Spectral reflectances. Changes in sun position, atmospheric attenuation, clouds, and viewing angle of the target are constraints on the sensing of objects through an atmosphere. Biological variation between plant varieties (i.e., leaf size, shape), degrees of maturation, and plant vigor among the same species contribute to spectral variations which are difficult to analyze from aircraft and from Landsat imagery (ref. 5).

2. Image quality. The variables in film emulsions, of over and under-exposure, and quality control in processing can contribute to significant differences in interpretation of crop stress and vigor (ref. 9).

3. Platform stability. Changes in platform (aircraft or spacecraft) altitude, altitude changes, and rates of sensing are no longer serious problems, especially with gyromounted sensors and the use of stable high altitude platforms like the U-2 or Landsat. However, with light aircraft at low altitudes, such variations can present constraints worth considering.

Application of Remote Sensing to Agriculture

Parameters relative to agricultural productivity to which remote sensing might apply are based on the identification of crop types and measurement of acreages, crop yields, growth rates, insect and disease detection and drought monitoring. Table 6-2 presents evaluations of remote sensing systems in the light of their ability to determine accurately various agricultural parameters. Criteria are detectability and ease of identification and mapping. Despite the subjective nature of the feasibilities shown in the matrix, the parameters selected to evaluate the remote sensing systems are appropriate to this study.

Currently, NASA's primary activities in remote sensing of agriculture involve the Large Area Crop Inventory Experiment (LACIE) and Earthsat Spring Wheat Yield Model. Both investigations utilize Landsat data.

LACIE, a joint effort by USDA, NOAA, and NASA, combines crop area measurements of wheat in the Northern Great Plains from Landsat imagery, meteorological information from NOAA (ITOS) satellites, and ground truth information. Based on a background technology of earlier multispectral and meteorological investigations, the experiment utilizes computer-aided image analysis and analyst-interpreters to examine the wheat in 637 sample areas. Each sample area is 100 sq. km (5 nm X 6 nm). The ultimate objective is to expand technology and establish procedures to be applied to inventory other crops in other regions and ultimately lead to global applications (ref. 6).

The Earthsat Spring Wheat Yield System Test is a unique procedure tested in the hard red spring wheat regions of North Dakota, South Dakota, Montana, and Minnesota in 1975. Largely automated with a potential for global application, the system combines ground meteorological observations and meteorological satellite (NOAA) cloud observations to determine daily estimates of the weather environment of the wheat plant. The main objective of the meteorological analysis is to define weather which influences plant growth with sufficient detail to permit an estimation of the growth stage of wheat. Yield, then, is derived from the growth stage of the plant based on daily plant stress. If the plant is "on schedule" because of ideal weather conditions, then yields will be high. If the crop has experienced plant moisture stress from drought, then yield predictions must be adjusted. The model thus utilizes information on daily weather environment of the crop, determines plant stress, uses Landsat data for area measurements, and determines yield forecasts. Results from the study showed errors in yield forecast to be -8% for Montana, +4% in North Dakota, -6% in South Dakota, and +8% in Minnesota with aggregate errors of +2% for the entire area (ref. 7).

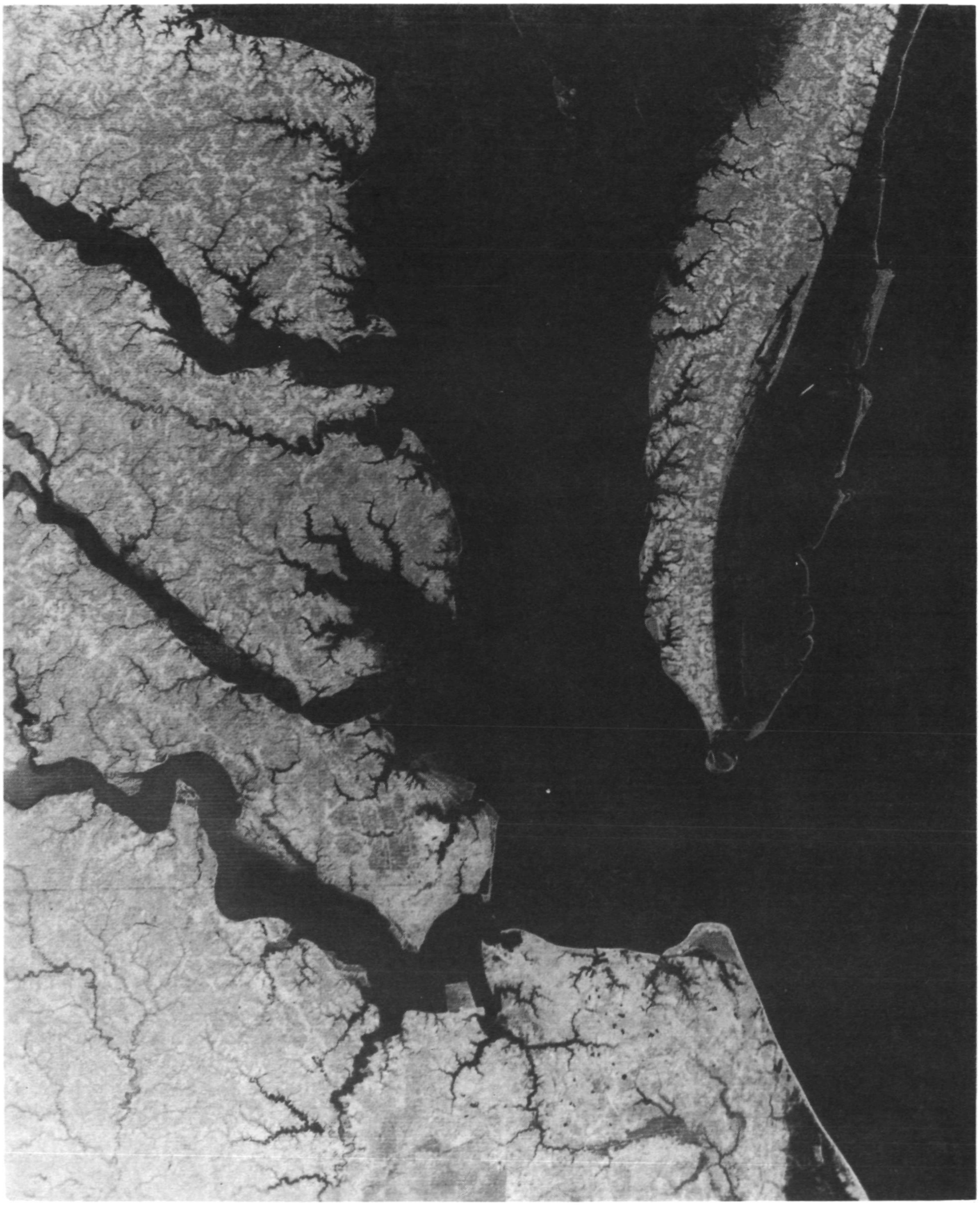

FIGURE 6-3 LANDSAT IMAGE OF LOWER CHESAPEAKE BAY

FIGURE 6-4 HIGH ALTITUDE AIRCRAFT IMAGE OF HAMTON ROADS AND JAMES RIVER BRIDGE.THIS AREA IS IN LOWER CENTER OF FIG.

Table 6-2

AGRICULTURAL PARAMETERS AND REMOTE SENSING SYSTEMS

PARAMETER	LOW ALTITUDE AIRCRAFT 1:10,000 MAP SCALE	HIGH ALTITUDE U-2 1:100,000 MAP SCALE	LANDSAT I-II 1:1 MILLION MAP SCALE	FUTURE LANDSAT,D 1:1 MILLION MAP SCALE
CROP IDENTIFICATION	1 / 123	2 / 123	3-4 / 1	3-4 / 123
AREAL MAPPING OF CROP ACREAGE	1 / 123	2 / 123	3-4 / 123	3-4 / 123
MONITORING CHANGES IN ACREAGE	1 / 123	2 / 123	3-4 /	3-4 / 123
FIELD SIZE	1 / 123	2 / 123	3-4 /	3-4 / 123
CROP YIELD FORECAST	1 / 123	2 / 123	3-4 / 123	3-4 / 123
PHENOLOGY (GREEN WAVE)	1 /	2 / 1,2	3-4 / 123	3-4 / 123
INSECT AND DISEASE DAMAGE	1 / 1,3	2 / 1,3	3-4 / 1,3	3-4 / 1,3
MONITORING DROUGHT	1 / 123	2 / 123	3-4 / 123	3-4 / 123

NUMERATOR: OPTIMUM AREA

1. County (1200 km^2)
2. State (120,000 km^2)
3. Nation (1,200,000 km^2)
4. Global

DENOMINATOR: INTERPRETATION FEASIBILITY

1. Detection
2. Identification
3. Mapping

- - - Feasibility doubtful

Recommendations from the two studies reveal common objectives. Inventory procedures and yield models should be applied to major crops in addition to. Further, such experiments should be applied to other agricultural regions in theU.S. and ultimately to agricultural regions throughout the world.

Summary of Uses of Remote Sensing in Agriculture

The following list summaries the principal uses of remote sensing in agriculture:

1. Inventorying crops.

2. Obtaining weather and climate data.

3. Determining water supplies and types of soil available for various projects.

4. Monitoring plant cover of rangeland.

5. Inventorying of timber in forests.

6. Detection of forest fires.

7. Monitoring of thermal and chemical pollution of marine waters.

Recommendations for Expanding the Effectiveness of Remote Sensing

1. Continue research and technology (R & T) in spectral signatures of crops.

2. Develop R & T in the thermal infrared remote sensing of agriculture utilizing Landsat-C and the satellites which will evolve from it.

3. Support research in global phenology (green wave) for world food crops and correlate Landsat imagery with meteorological data from satellites.

4. Support research in optimum field sizes and patterns for Ag-Air applications. These parameters could be determined spatially from high-resolution satellite imagery. Even a global index of areas of optimum field size and pattern might be realized.

5. Support research which utilizes historical and current Landsat data to establish and monitor variables in selected crop types, acreages, and yields in the U.S. and in foreign areas.

6.2 Information Systems Technology and Management

Introduction

The key to full utilization of remote sensing data from satellites is improvement of the reliability and the timeliness of the data. Currently, information generated by satellite telemetry is used primarily by researchers, not by practitioners. When information can conveniently be made available to the field practitioner, satellite remote sensing will become a permanent fixture. The two studies previously mentioned, as well as others concerned with water-quality monitoring and wide area disease detection, offer great potential benefits, but the techniques must be made operational in a production sense before their acceptance is assured. Transition from experimental demonstrations to an ongoing production process is dependent upon additional technological improvements as yet unavailable.

Projected information generation rates for the year 2000 indicates that 10^{13} to 10^{15} bits of data will be received daily from earth-applications satellites; this quantity of data is equivalent to an accumulation of thirty Libraries of Congress per year (ref. 8). Given the current level of information-handling technology, this constitutes an impossible deluge. Indeed, large stores of data are still backlogged from previous missions awaiting analysis. Much of this information becomes obsolete before it is ever accessed for analysis. Part of this problem may be solved by the use of selective surgery; that is, the removal of certain information from the transmission stream of the satellite. To some degree selectivity is utilized at present by activating the satellite only during specific portions of the orbit. Technological developments foreseen for the very near future indicates that considerable data screening, data reduction, and interpretation may take place on-line and on board the satellite. This processing would enable the data transmission stream to contain a much higher information content.

Although such techniques will alleviate the problem to some extent, there will be an increasingly strong technical pressure to produce more sophisticated remote sensing devices capable of generating considerably more information than is currently possible. A further problem arises as it becomes increasingly necessary to incorporate aircraft remote sensing data and satellite data to produce multistage data montages. Obviously, the volume of information in such representations is greatly increased; far more sophisticated data processing techniques are required to facilitate the utilization of these products.

Future developments in computer technology point towards evolutionary changes instead of revolutionary jumps. These changes should permit considerably greater levels of computing power per pay-load weight; thereby making the satellite more cost effective. Continued improvement in computer reliability and self maintenance will greatly extend the operating life of the satellite system. These advances in the power and capability of on-board computer systems will permit a significant expansion of data manipulation, screening and preprocessing prior to earth transmission. Such scrubbing will be helpful in reducing the volume of data processing required at the ground stations and permit ground computers to concentrate, to a large extent, upon the information analysis phase.

It is quite possible that, as the utilization of remote sensing increases and its attributes of resolution and timeliness improve, end users may receive information directly from satellites. An example of such a possibility is the directing of fishing fleets to productive fishing grounds through real-time continuous monitoring of the seas by satellites. Such techniques have been demonstrated to be feasible in situations where information lag was less than 21 hours (ref. 9).

The LACIE experiments have demonstrated the value of remote sensing information in making predictions of crop production. As remote sensing techniques improve, it is conceivable that near real-time information could be incorporated into the decision-making process of growers and government planners, thus permitting more effective control of annual crop production (ref. 10).

Remote Sensing Information Usage

An urgent concern in practical utilization of remote sensing is the ability to provide timely and reliable data. Information dissemination, as currently practiced, is a four-stage process, as shown in Figure 6-5. Satellite imagery is gathered and transmitted to earth at Goddard Space Flight Center. Here digital tapes are prepared and then sent by mail to EROS Data Center in South Dakota. Potential users may then make requests for specific imagery which will be processed and the requisite imagery mailed to the user. It is obvious that current methods of dissemination are cumbersome and the many inherent delays cause the average time from image acquisition to end user to balloon to eight or ten weeks. Such a lag time is, of course, prohibitive when near real-time responses to the data are desired. It is also surprising that a considerable proportion of this delay is due to the U.S. mails (4 to 6 weeks). Even if the mail lag were removed, however, the turnaround is still completely inadequate for near real-time decision making.

A second problem is time-reliability of remotely sensed satellite data. The equipment currently aboard satellites does not yet permit effective collection of data through extensive cloud cover. Since large parts of the world are often under cloud cover, it may not be possible to obtain clear imagery and the desired level of continuity will be lost. The problem of timeliness can be solved to some extent by currently available technology; however, cloud cover penetration capabilities are still at an evolving stage with some extended capabilities expected from Landsats C and D.

Technical advances in remote sensing for agricultural application will be realized in three areas: data acquisition (advances in sensor technology), storage (progress in computer technology).

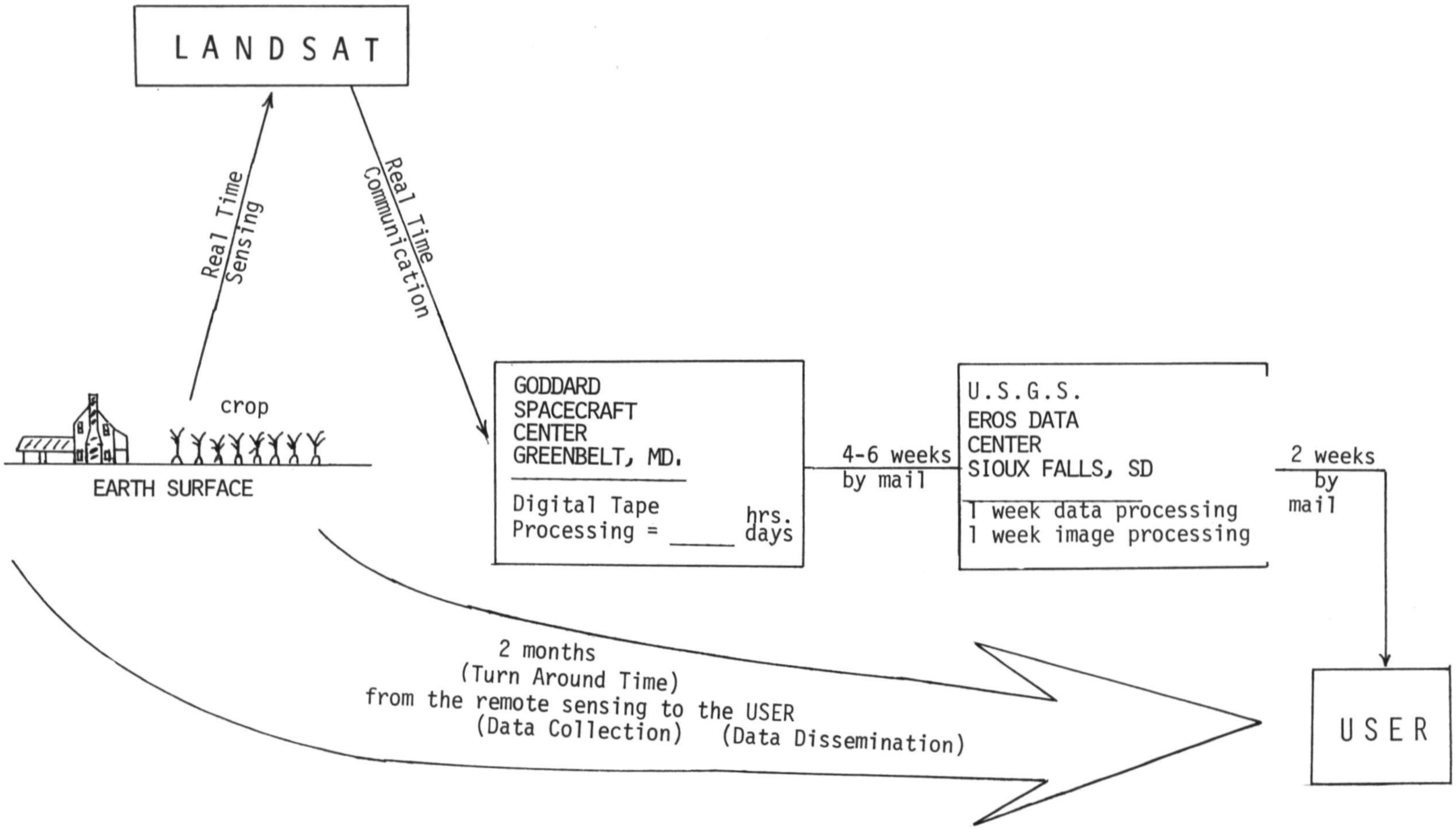

FIGURE 6-5 SENSOR-USER TIME LAG

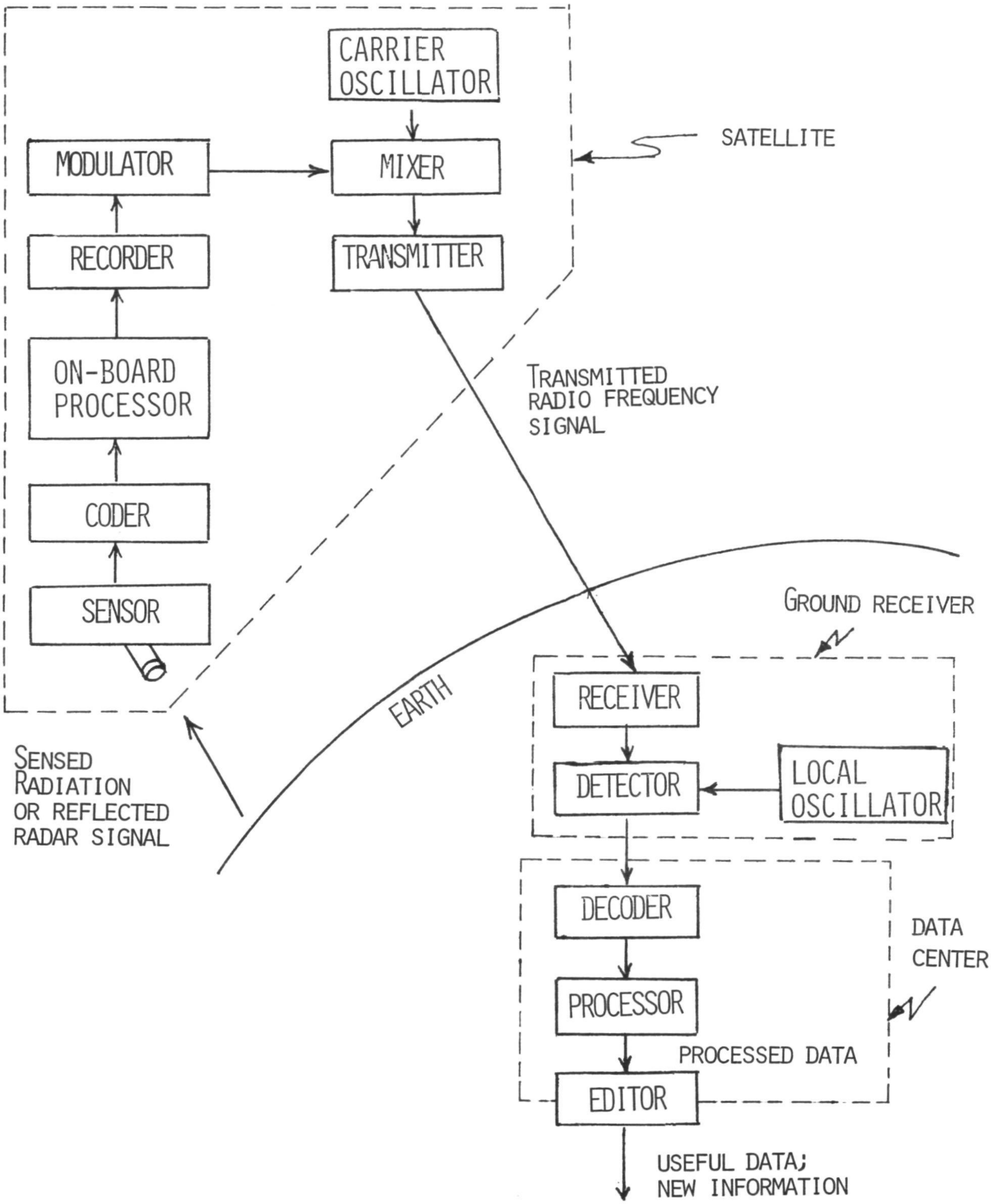

FIGURE 6-6 FLOW OF INFORMATION FROM ORBITING SENSOR TO USER.

Figure 6-6 shows flow of information from the orbiting or airborne sensor to the user, but with emphasis on the hardware components. Depending on satellite design, the chain may or may not include a recorder, which plays back only at prearranged times or upon command from the ground. The entire scheme must be treated as a system. Improvement of each step of the chain is discussed below.

Technological Developments which Enhance the Value of Remote Sensing

Improvements in sensors such as the microwave radiometer, infrared detectors, and multispectral images will depend on attainment of lower equivalent noise temperature and increased aperature size. The former places a limit on detector sensitivity. If the equivalent noise temperature of a sensor can be kept very low, then very weak signals can be detected without being masked by noise. Research in cryogenic cooling of detector circuitry should lower the present extent of noise to be reduced by one, or possible two, orders of magnitude. Aperture size, together with sensed wavelength, determines the angular resolution of the sensor. Presently, the best obtainable angular resolution is some tens of microradians, which results in linear resolutions of about five meters on the ground, from the altitude of a typical earth orbit. Research toward increased aperture size (either physical or effective) should bring this down to two meters in the next 15 years (ref. 11).

Better ways for utilizing the electromagnetic spectrum for information transfer will bring about greater capabilities in remote sensing:

> The production of electromagnetic radiation power has progressed through four prime energy reactions in the past 75 years, evolving from spark discharges of the old gap transmitters to the electron beam interactions of linear-beam tubes to the hole-electron flow of solid-state devices and to the atomic resonance of lasers. What is of interest is that no prime radio frequency reaction has been discovered in the past 35 years. An innovation is seemingly overdue, and with our accumulating technical wherewithal, it is likely to come before the present decade is past - in view of the present emphasis on energy research. Energy production will reach the status of a national goal and the research surrounding this activity will receive wide public funding support. The next radio-frequency reaction phenomenon will be discovered either directly or as a side-effect of this tremendous nationwide scientific activity. Energy of one form is required to produce energy of another form, and the level of energy research destined for the nest ten years will bring forth many useful power reactions. It is expected that among these will be a new rf transmitter powered by a simple energy source (ref. 12).

Until this breakthrough occurs, hardware improvements in electromagnetic transfer of information will continue to be realized through improvements in various components of radio or laser links (transmitters, receivers, antennas) and techniques for signal coding, modulation and bandwidth compression. New solid-state electronic devices, possibly cryogenically cooled, with very low

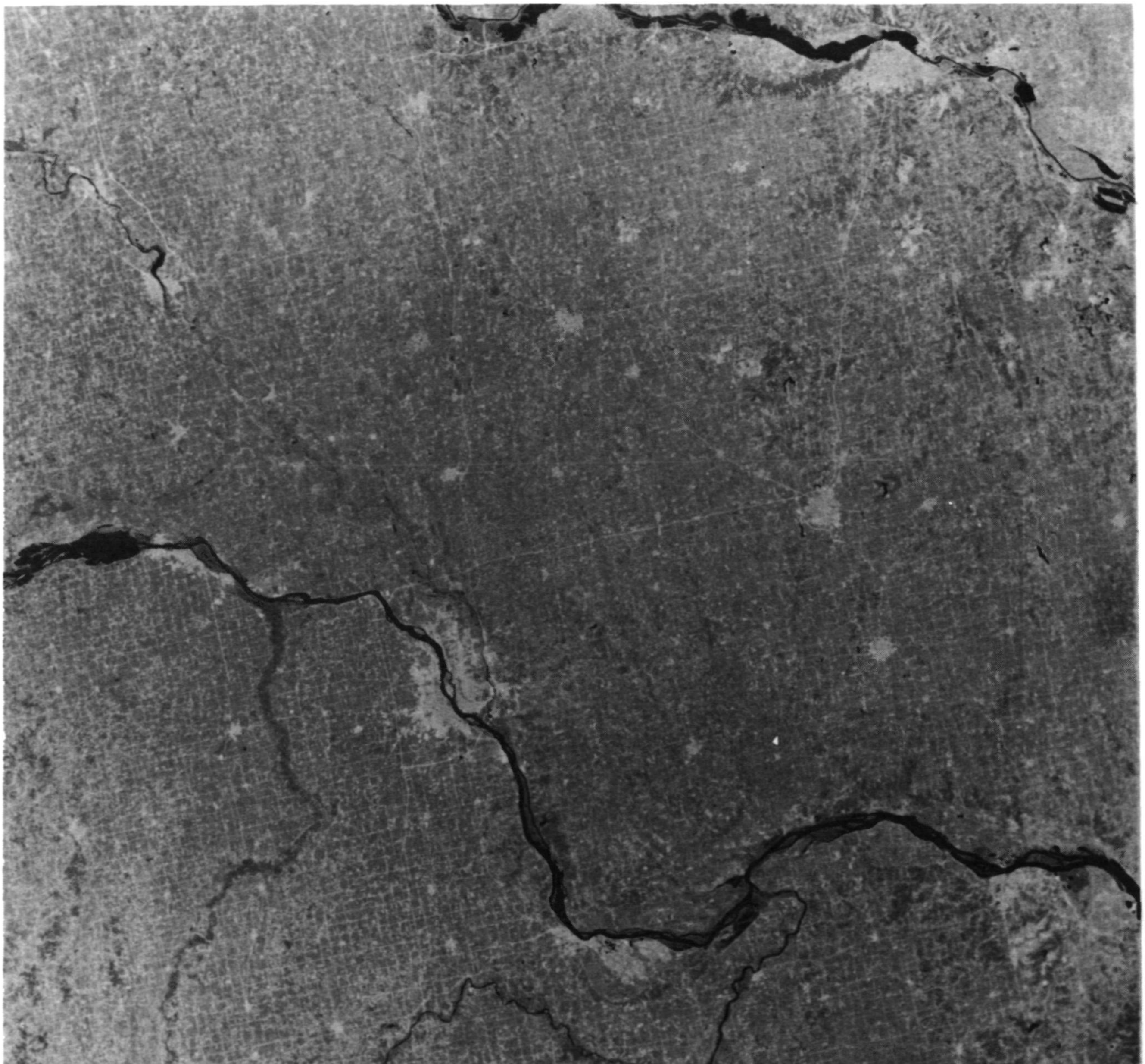

FIGURE 6-7 LANDSAT IMAGE OF CORN BELT AREAS OF ILLINOIS AND INDIANA

equivalent noise temperatures, must also be developed for use in receivers. Finally, phased-array antennas, and other schemes for enhancing the directivity, signal-gathering and signal-directing ability of telemetry links must be improved.

As more remote-sensing satellites are placed into orbit and the time rates of information transmission become greater, competition for available radio bandwidth will become acute. For additional bandwidth, satellite users must compete with users of numerous other radio services for whatever small portions of the electromagnetic spectrum are not yet committed by international agreement.

To obtain maximum efficiency from the wavelength bands now assigned for scientific satellites, new techniques in coding, modulation, and radio bandwidth compression systems are needed.

Laser communication is a fruitful area of research; environmental satellite users await the advent of operational tunable lasers for data links. One advantage of laser telemetry over conventional microwave radio is that several lasers operating on the same carrier frequency will not interfere with each other. This is so because the beam emitted from a laser is coherent and produces no off-beam interference with other laser beams. Thus, frequency allocations are not necessary; the only limits on available bandwidth are the modulation system used, and the small number of laser types that react efficiently.

On-board editing and pre-processing of the signal before transmission or recording will do much to alleviate demand for increased radio bandwidth. This would simultaneously help solve the problem of terrestrial data centers becoming deluged with data, not all of which are useful. The higher the ratio of total data to useful data, the more difficult it is to access the useful data.

Once on the ground, the signal is demodulated and decoded in accordance with the coding and modulating schemes applied before transmission. Further processing may include signal enhancement through transformation or correlation techniques, and, in the case of imaging, pattern recognition. These steps typically involve large computers, and thus are performed at one or two specialized data centers.

Earlier reference was made to the tremendous growth in the quality of remotely sensed data available from satellites. It is currently the responsibility of the EROS Data Center in Sioux Falls to attend to problems with this information. As the volume of information increases, it becomes feasible to consider regional data centers. Information processed by Goddard could be selectively distributed to appropriate regional centers or could conceivably be transmitted directly to the respective regional centers from the satellite. This direct tranmission could be realized only if the detection, decoding, and subsequent processing could be kept simple enough. Such an arrangement would permit more concentrated attention on problems associated with specific regions and would probably facilitate integration of aircraft-remotely sensed data with those obtained via satellite.

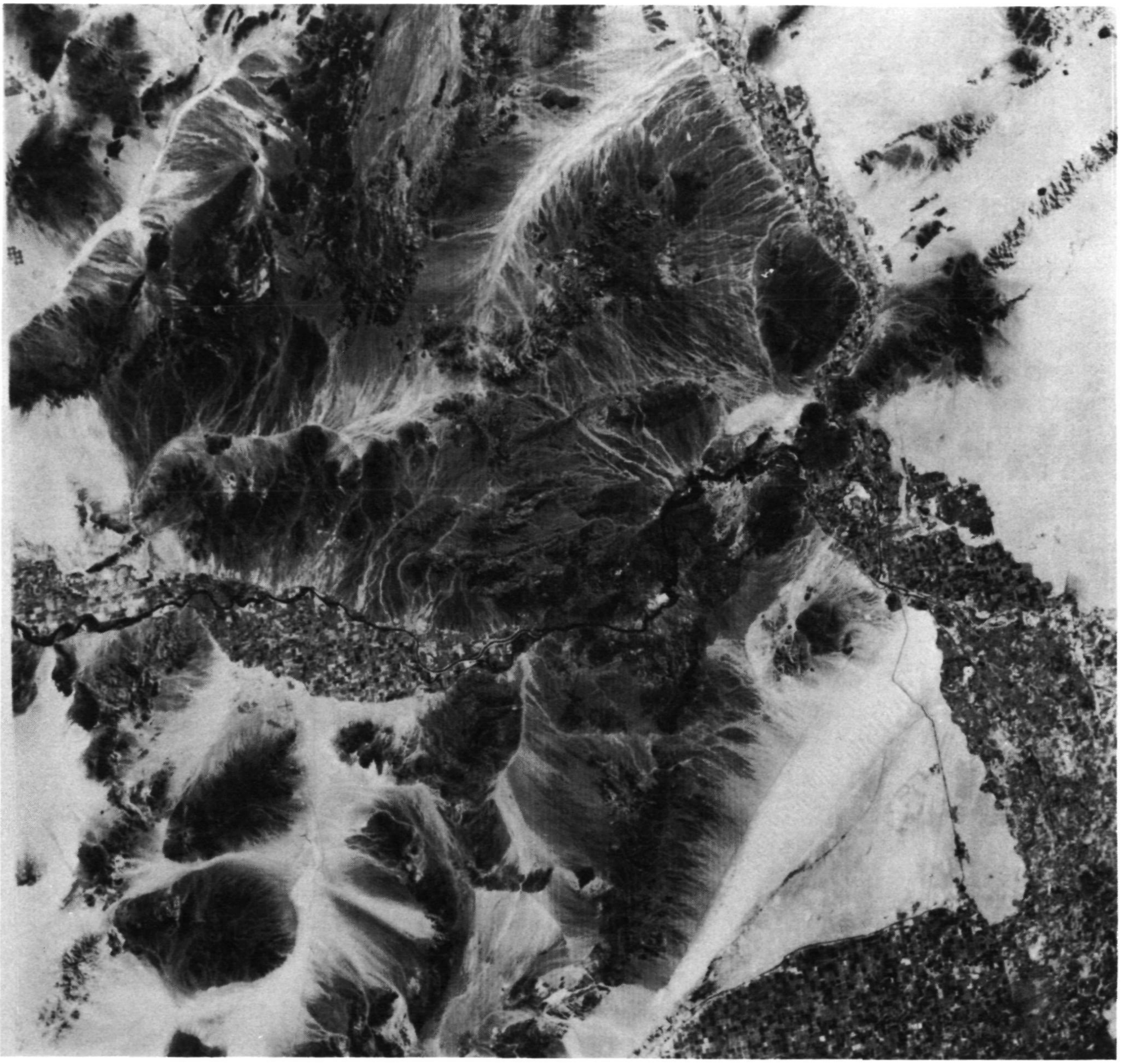

FIGURE 6-8 IRRIGATED AGRICULTURE IN THE IMPERIAL, GILA RIVER AND LOWER COLORADO RIVER VALLEYS

Individuals at these regional centers would be much better informed as to problems and opportunities approachable through remote sensing. Additionally, these individuals would have greater opportunity for a dialogue with state and county officials whose data needs could be variable over a short time span.

Recommendations for Further Development of Remote Sensing Capabilities in Agriculture

Resulting from the preceding discussion, three areas of study are proposed. This study would permit a unified solution to the problems involved in disseminating remote sensing data:

An in-depth survey of current users of remote sensing data should be undertaken. The survey should reveal the types of users who currently utilize remote sensing for research as opposed to routine activities, and the degree of reliability and timeliness required by specific categories of researchers.

A second study should be undertaken to identify potential users of remote sensing data. These individuals may or may not have a need for the quality of data currently available from remote sensing. If future improvements in remote sensing capabilities would serve their needs, then these individuals should be identified.

A thorough evaluation of the procedures currently used to disseminate data produced by satellite remote sensing should also be undertaken. Particular attention should be paid to areas where dissemination time could be reduced at a low cost. Also, the feasibility of regional browsing centers should be examined in the light of the distribution to current and future users of remote sensing imagery.

Research leading to improved and more varied spaceborne sensors, better utilization of the electromagnetic spectrum for information transfer, more efficient coding and modulation schemes, and new transmitter and receiver designs should be continued.

6.3 WEATHER AND CLIMATE

Importance of Weather and Climate

In a very real sense, we are at the mercy of weather and climate. Fluctuations in weather and climate cause the largest variations in food production (ref. 13, p. 83). According to the Food and Agriculture Organization, as reported in the May 22, 1977 New York Times, the difference between an adequate food supply and a world food crisis represents only five percent of a year's total grain production. An unfavorable crop year, such as occurred in the Ukraine in 1972, has immediate international consequences. As the population of the world increases and as newer nations continue their economic development, demand for food, water, and energy will continually become greater, but the supply of these requirements will remain subject to vagaries of weather and climate unless drastic improvements in planning and management are made.

Complicating this problem is the fact that the present climate is abnormal. "Only during about eight percent of the past 700,000 years has the earth experienced climates as warm or warmer than the present" (ref. 14, p. 181). Natural events or human activities may change climate significantly.

Climate connotes average weather. Weather is usually described by the temperature, humidity, precipitation, wind speed and direction, air pressure, and amount of sunlight. Weather occurs in the lower level of the atmosphere, the troposphere, which extends from the surface to an altitude of about 11,000 meters (36,000+ feet).

The Sun

The atomosphere of the earth may be described as a heat engine driven by the sun. Because of non-uniform heating and cooling, a primary or general circulation is set up on the rotating earth. The large scale waves and eddied in the atmosphere modified by the terrain produce the climate patterns of the world, (ref. 15, p. 756). To understand weather and climate, it is necessary to start by studying the sun. The sun is a distant, massive, hot object that emits energy as a consequence of internal nuclear reactions. The sun radiated electromagnetic energy as though it were a black body. Almost half of the sun's radiation is visible, but an appreciable fraction of thepower is emitted in the near-ultraviolet and near-infrared parts of the spectrum (ref. 16, p. 500). Solar radiation is most intense in the yellow portion of the visible spectrum.

Agriculture is primarily based on the chemical processed called photosynthesis, given in simplied form as follows:

$$CO_2 + H_2O \rightleftarrows CH_2P + O_2$$

In the presence of sunlight, with the aid of chlorophyll acting as a catalyst, the reaction proceeds to the right. Carbon dioxide and water combine to form starch and oxygen. All plant cells respire, and therefore the reverse reaction proceeds independently to the left at all times. Only the leftward reaction occurs at night or within those cells that do not contain chlorophyll. Since chlorophyll reflects green light, only the red and violet ends of the visible spectrum are actually absorbed by the plant during photosynthesis. Most of the incident solar energy is not used by plants, with less than three percent of the incident solar energy being ultimately converted by a plant into stored chemical energy.

Power emitted by the sun may vary cyclically. Sunspots are dark areas over the surface of the sun, probably indicating intense activity beneath these spots. The number of sunspots usually increases from zero to a maximum of 150 and then declines again to zero during an 11-year cycle. The time average number of spots is 80. A group at the Smithsonian Astrophysical Observatory and a group in the Soviet Union have related the number of sunspots to the solar "constant", the power received per unit area at the outer limits of the earth's atmosphere. The relation is (ref. 17):

$$S(N) = 1.903 + 0.011\,(N)^{\frac{1}{2}} - 0.006N \text{ Cal/min per sq cm}$$

where S(N) is the solar constant and N is the number of sunspots. As N varies S(N) fluctuates approximately two percent about its average value. It should be noted, however, that the average of the various measured values of the solar "constant" has an estimated error of two percent (ref. 18, p. 1687). Clearly, the proposed variation of S(N) is of the same order of magnitude as the estimated error of the solar "constant." The relation of the solar "constant" to the number of sunspots should be investigated in greater detail. A varying output of the sun may have important effects on weather and climate on the earth.

Near the plane of the ecliptic, the sun appears to be surrounded by a magnetic field that is divided into four sectors as shown in Figure 6-9. A fundamental problem is to explain how the oppositely-directed fields are maintained side by side in interplanetary space filled by charged particles ejected from the sun (ref. 20). Since the rotation period of the sun is approximately 27 days, the earth is in a solar magnetic field of opposite polarity every seven days. Apparently the creation of vortices in the lower atmosphere of the earth is in some way linked to this phenomenon (ref. 21). Work on this problem is proceeding at several institutions, and additional support should be given to this effort.

The Earth

Mankind lives on the thin cracked outer shell of a "hot radioactive soft-boiled egg." This is a graphic description of the main geologic features of the earth as a whole. The average radius of the earth is 6,731 km (4,182 mi) and its mass is 5.975×10^{24} kg (132×10^{24} lb).

The center of the earth travels in a nearly circular elliptical orbit around the sun, the average distance of the earth from the sun being 1.495×10^{8} km (9.29×10^{7} mi) as shown in Figure 6-10. The axis of the earth is at present inclined 23.5^{0} to the normal to the plane of the orbit (ecliptic). This angle may vary from 22.1^{0} to 24.5^{0} with an average period of approximately 41,000 years (ref. 22). The axis of the earth is also precesses with a quasi-period of 23,000 years, much as the axis of a spinning top changes direction in space. Finally, the shape of the earth's orbit varies from a nearly perfect circle to a somewhat pronounced ellipse with an average period of 93,000 years. All of these changes have in the past 4 million years produced variations in climate. "A model of future climate based on the observed orbital-climate relationships, but ignoring anthropogenic effects, predicts that the long-term trend over the next several thousand years is toward extensive Northern Hemisphere glaciation" (ref. 22).

The most pervasive feature of the earth is the fact that it exerts a force of gravity on all objects on or near its surface. All higher forms of life have adapted to gravity. To answer important questions about living and working in space, we must maintain selected life forms in a weightless environment sufficiently long to allow zero-gravity adaptive patterns to develop and

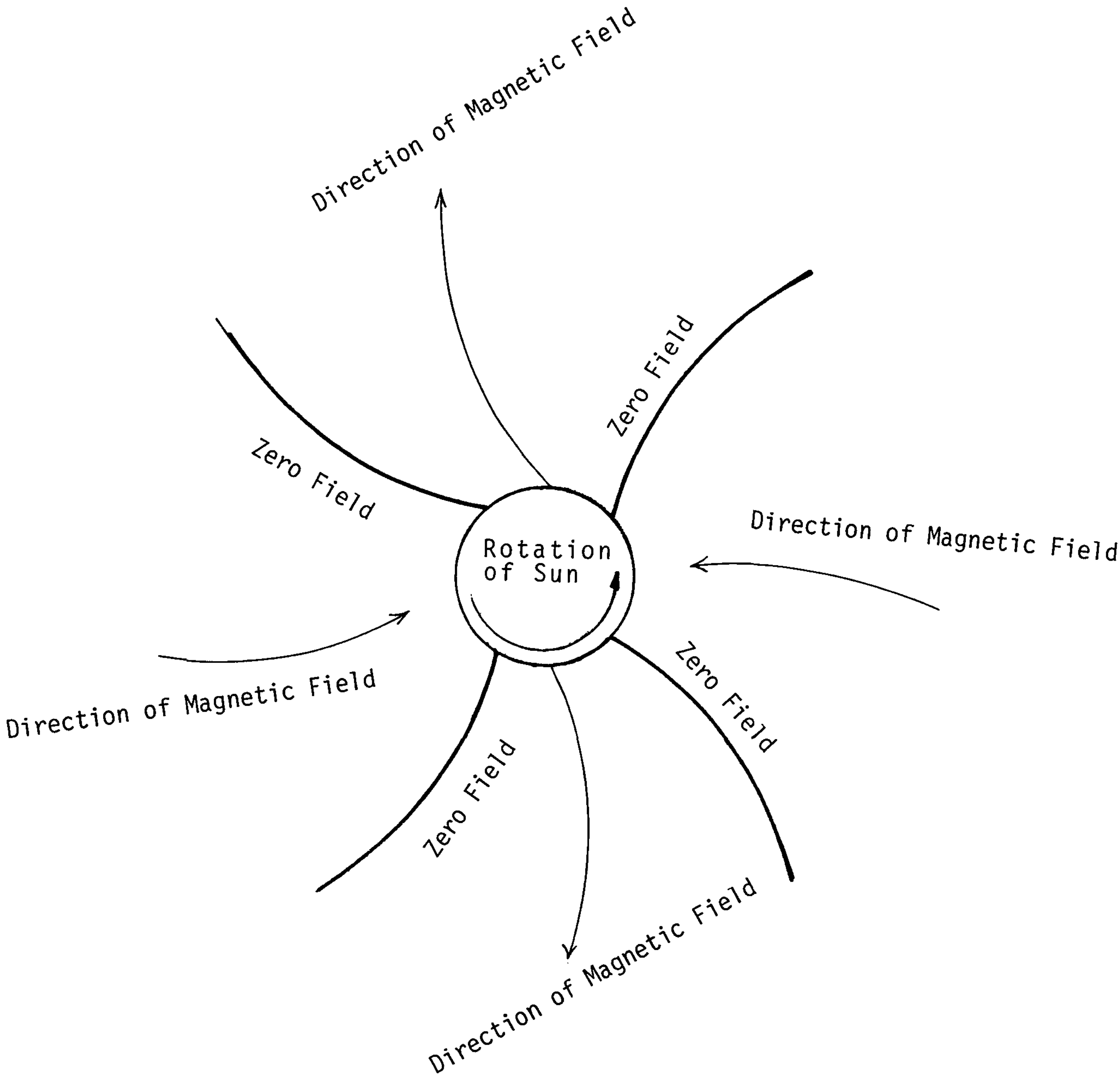

FIGURE 6-9 THE SUN ROTATES WITH A PERIOD OF APPROXIMATELY 27 DAYS AND CARIES WITH IT MAGNETIC FIELD CONSISTING OF FOUR SECTORS OF ALTERNATING POLARITY NEAR THE PLANE OF THE ECLIPTIC.

stabilize (ref. 19, p. 100). There have been proposals for space station farms in which plants and animals will be bred and raised in zero or low gravity environments. Useful structural changes may result (See Chapter 8).

The Atmosphere

The atmosphere is the stage on which the drama of weather and climate is played. The atmosphere is considered to consist of five layers defined by the way the air temperature varies with altitude. In the lowest, the troposphere, temperature decreases linearly as altitude increases. The upper boundary of the troposphere, the tropospause, is about 11 km (36,000 feet) at middle latitudes, but varies from about 16.5 km (54,000 feet) at the equator to 8,500 m (28,000 feet) at the poles. The troposphere is composed of about 80 percent molecular nitrogen and 20 percent molecular oxygen.

The stratosphere extends from the tropopause to an altitude of a bit less than 50 km (30 miles). In the lower part of the stratosphere (from tropopause to about 107 km (67,000 feet) altitude) the temperature is constant - 56.5°C (-69.7°F). In the upper regions of the stratosphere there is strong absorption of solar ultraviolet radiation by ozone which protects the earth's surface from this radiation and produces the high temperature region (-2.5°C, 27.5°F) near the base of the mesosphere, which extends from the stratosphere to about 80 km (50 miles). Above these regions are the thermosphere (ionosphere) and the exosphere which are of interest only to satellite performance.

Almost all of the effects associated with weather occur in the troposphere. Here is where winds blow, clouds form, precipitation occurs, and temperature rises and falls. The broad features of atmospheric dynamics and energy balance are understood, but a number of questions remain. Some of these are (ref. 19, p. 109): What is a front? How are they formed? What is the mechanisms of tornado, hurricane, or typhoon formation? How can we predict the paths of severe storms?

An additional problem in connection with the troposphere is pollution. Lead particles from automobile exhausts or aerosol particles may serve as nuclei for condensing water vapor and thus result in increased precipitation which in turn can have a cooling effect (ref. 23). A particular danger to agriculture is high concentration of ozone (ref. 18, p. 1686). It may well be that tropospheric ozone is brought down to the surface when a cold front approaches. In comparison to the movement and turbulence encountered in the troposphere, the stratosphere is relatively quiet. Consequently, only long-term changes in weather and climate are related to variations in the stratosphere. The primary parameters of concern are ozone, dust, aerosols, and CO_2. The ozone layer provides a shield for living things on earth. "One potential problem is a predicted depletion of stratospheric ozone due either to operation of high-altitude aircraft and/or the release of fluorocarbon aerosols into the atmosphere. A Harvard University team predicts ozone depletion of between 3 and 30 percent by the year 2000 depending on the rate of industry growth, aircraft operation, and government regulation" (ref. 19, p. 67). Climatic effects are of particular concern since they can affect global food supply. It is important to monitor and analyze the changes in stratospheric ozone.

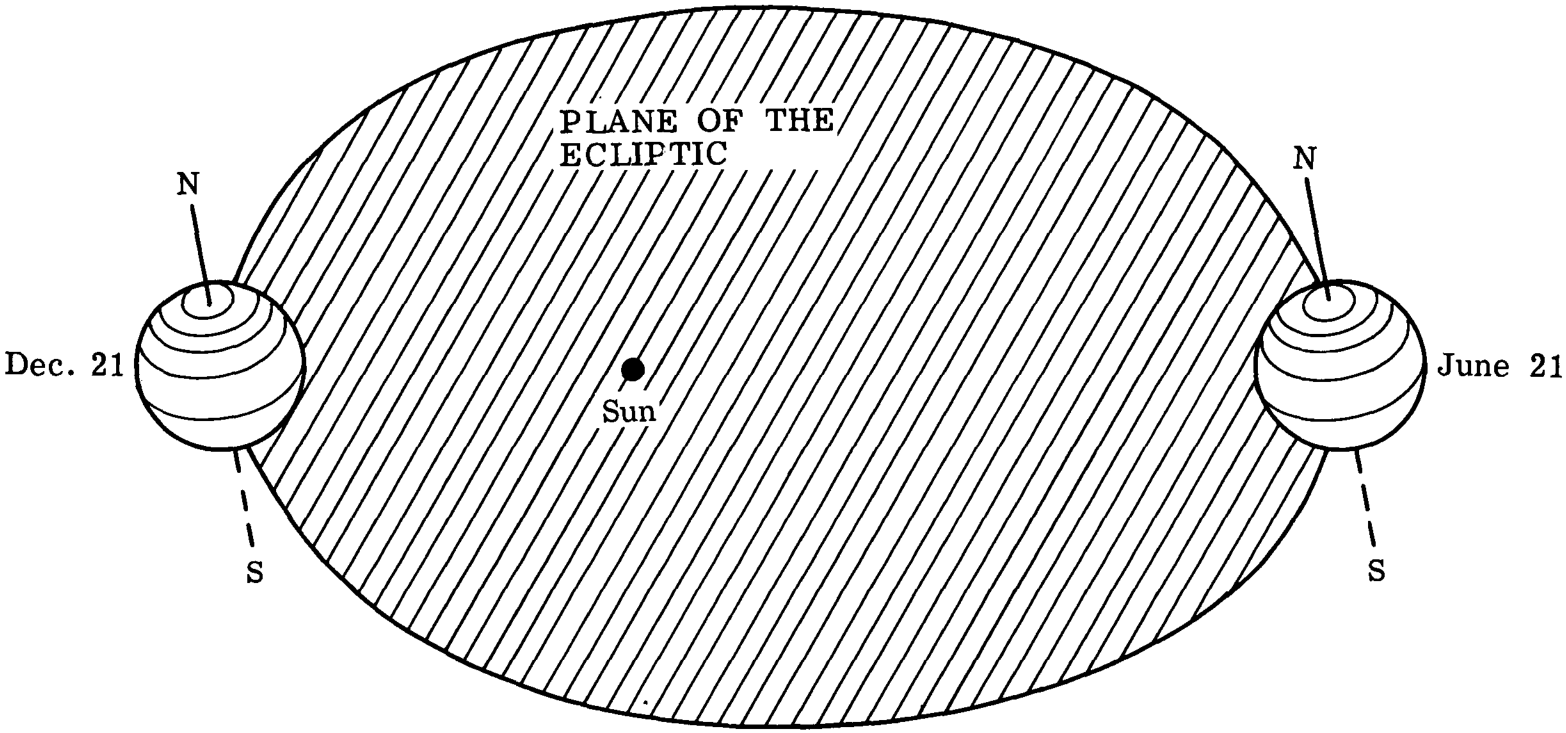

FIGURE 6-10 THE EARTH TRAVELS IN A NEARLY CIRCULAR ELLIPSE AROUND THE SUN. THE AXIS OF THE EARTH IS INCLINED 23.5 DEGREES TO THE NORMAL TO THE ECLIPTIC.

Carbon dioxide in the stratosphere has a "greenhouse" effect"; that is, high frequency radiation from the sun is transmitted through the gas, but the lower, frequency radiation emitted upwards from the earth is absorbed. The result is that the earth has a higher temperature than it would without the greenhouse effect. "The amount of carbon dioxide released has been increasing by about 0.2 percent per year, primarily because of the burning of fossil fuels. It is estimated that a ten percent increase in carbon dioxide would increase temperature between 0.5°F and 0.6°F" (ref. 23). Of course, a higher temperature would result in increased evaporation and a greater cloud cover, with the result that the earth would receive somewhat less radiation, offsetting, to a certain extent, the greenhouse effect.

Dust or aerosol particles in the stratosphere reflect light and consequently decrease the amount of solar energy received by the earth. The result is a cooling effect. In this case, a lower temperature would result in decreased evaporation and a lesser cloud cover. Thus, the cooling effect due to particulate matter would be diminished to a certain extent by the change in rate of evaporation. It is important to monitor and study the anthropogenic effects on the atmosphere since life on earth is clearly affected.

Climate

Climate is usually defined in terms of the average weather. The composition of the atmosphere near the surface of the earth is also a significant factor in climate since it often has a direct effect on human beings, animals, and crops. Chemical interactions in the atmosphere may change its composition and consequently its physical properties. Further, the biosphere affects climate by modifying the rate of evaporation of moisture and the extent of reflection of light. Thus, in a broad sense, climate is a description of the average state of the atmosphere, which in turn depends on physical, chemical, and biological interactions.

The two most important factors in climate are temperature and moisture. Without water, photosynthesis cannot proceed; plants must have adequate moisture. Temperature is also a crucial factor in plant growth. Respiration, the oxidation of the products of photosynthesis, proceeds more rapidly at higher temperatures. At very low temperatures, plants cannot respire, and at relatively high temperatures photosynthates are rapidly used up. Crops grow best under certain optimum conditions that are usually somewhat different from the "normal" climatic conditions.

Climatic conditions are of great economic importance. Table 6-3 gives some representative figures for the loss to the United States, in billions of 1973 dollars, for a decrease of 1°C without a change in moisture conditions (ref. 25, p. 15).

TABLE 6-3

ESTIMATED ANNUAL ECONOMIC LOSS DUE TO A 1°C DECREASE IN MEAN ANNUAL TEMPERATURE OF THE UNITED STATES

Economic Activity	Billions of Dollars Lost
Wheat and Rice Production	1.0
Forest Products	2.2
Marine Resources	1.4
Added Health Costs	2.4
Commercial Electrical Demand	-0.7 (- indicates gain)

Clearly, a small change in mean annual temperature may have a billion-dollar impact on agriculture.

There are a number of theories of change in climate. The assumption that is usually made is that the climate system responds to one or more of the following forcing functions: (1) continental drift, (2) fluctuations in solar radiation, (3) changes in stratospheric CO_2 content, (4) changes in stratospheric dust and aerosol content, (5) changes in albedo. The first cause listed above is probably of importance over a time span of millions of years. In this connection, it is interesting to note that coal is found in the Antartic so that vegetation must have grown there and the climate must have subsequently changed radically. The second cause of climatic change is probably of importance over a time span of tens of thousands of years. The great ice ages on earth have been explained on this basis. For purposes of assessing impact of climatic change on present-day agriculture, however, neither continental drift nor variations in earth's orbit and axes of rotation seem significant. The rate of change is simply too small. However, in the past a period of considerably colder climate has followed immediately after the interglacial period. Since about 10,000 years have elapsed since the onset of the present warm period, the earth may be on the brink of a period of colder climate. The other four causes of climatic change are of importance over time intervals of the order of decades or centuries. It appears, for example, that sunspots wax and wane during an eleven year cycle. The possible variation in solar output seems to be of the order of two percent. However, this figure is conjectural at present.

Any activity that alters the transparency or opacity of the atmosphere will change the greenhouse effect, and may ultimately produce variations in its temperature. The rate of increase of CO_2 in the air is approximately 0.7 parts per million per year. According to calculations of the net effect of altering the CO_2 content of the atmosphere (ref. 25, p. 155), doubling the CO_2 concentration in the atmosphere would lead, with the present average cloudiness, to an increase in the temperature of the troposphere, the world over, of approximately 2°C. However, since 1940, global temperatures have decreased while the CO_2 content due to man's activities has almost doubled. This apparent paradox indicates that changes in global temperatures cannot be attributed solely to changes in the composition of the air. Obviously, an important question is: as the production of CO_2 increases, will the atmosphere retain a greater percentage, or will the rate of absorption by the oceans and the biosphere increase? As mankind continues to increase burning of fossil fuels, the necessity to monitor CO_2 concentration will increase.

A unit increase in the albedo of the earth could bring about a drop in temperature of 0.8°C (ref. 25, p. 156). The albedo of the earth depends on the average cloud cover, average snow and ice cover, and the character of the land itself. Humans have reduced forests, eliminated swamps, built urban centers and concrete roads, and developed large areas for growing crops and raising cattle. These activities have appreciable effects on climate over small regions (ref. 19, p. 156). Decreasing plant cover over a large area, for example by overgrazing by sheep and goats, increases the albedo of the surface and thus causes a net decrease in the absorption of solar energy. This may have happened in the Negev Desert of Israel. A thousand years ago, this area was populated with people who maintained an agricultural economy.

Recommended Directions for Climate Research

A NASA study committee (ref. 19, pp 152-156) recommends the following program: (1) Data Base. Develop a body of information on climate and its variations with enough statistical accuracy to distinguish actual climatic trends due to real climate changes from normal weather fluctuations (climate noise); (2) Monitoring. Identify and monitor the factors that control and/or influence climate, determine the potential for change in each, and determine the climate's possible response to such changes; (3) Forecasting. Determine the predictability of climate on various time scales and, to the extent possible, develop a forecasting capability; (4) Human Effects. Identify and monitor activities of humans which may change the climate; investigate possible measures to counteract adverse changes or to bring about desirable changes.

The Interdepartmental Committee on Atmospheric Sciences (ICAS) recommends five broad activities (ref. 26): (1) Determine the importance of climate variations to food and fiber production, energy use, transportation, and other national activities; (2) Provide diagnosis and projection of short-term climate variability; (3) Develop climate theory, modeling, and simulation; (4) Establish a global observing system for climate research and services; (5) Develop data management in support of the above activities. Actually, the latter ICAS recommendations supplement and amplify the recommendations of the NASA study committee. Together they comprise very satisfactory directions for research in climate.

Weather

A study (ref. 27) was recently made of the value of improved weather information and weather forecasting to farmers and agricultural processors in the United States. Investigators began by identifying production and processing operations that could be improved with accurate and timely information on weather patterns. For example, summer rains often wash off pesticide applications before pest control can be realized. Unexpected winds increase the drift of pesticides away from target areas and make spraying operations more difficult and costly. Heavy harvesting machinery cannot operate in muddy fields.

After identifying those processes sensitive to short-term weather forecasting, estimates were made of the savings due to better management realizable with timely, accurate weather forecasts for 12-hour intervals. Such weather information has been called nowcasting. A reasonable estimate of the value of nowcasting is that it would increase the worth of the agricultural product by three percent.

Total economic losses due to weather are of the order of 12 billion dollars per year, of which five billion dollars are estimated to be preventable (ref. 19, p. 60). Better weather forecasts for periods up to 30 days could reduce these losses by an estimated 0.5 billion dollars per year. Clearly, accurate and timely near-term and long-range weather forecasts are of considerable value.

A model for predicing weather must describe the flow of an extensive fluid of non-uniform composition relative to a rotating coordinate system. The model must formulate the flow of mass, charge, energy, momentum, and entropy. The difference between a model for weather and a model for climate is the degree of detail that is needed. In a model for climate, the flow of energy is most significant whereas in a model for weather, the flow of mass and momentum are most important. The flow of charge may also prove to be significant inasmuch as the earth is in a varying solar magnetic field. The energy involved in magnetic field reversals is comparable to the energy involved in atmospheric motions.

Recommended Directions for Weather Research

The key to improved weather forecasts seems to be better models of the atmosphere. To reach this goal, global observations are essential, and satellites provide the chief practical method for obtaining the required data. Essentially what is needed is the air density, temperature, pressure, water-vapor content, and wind velocity at each point of a vast three-dimensional grid. The points of this grid should be spaced approximately 100 km (60+ miles) apart horizontally and 1 km (3,300 feet) apart vertically. Data should be recorded at intervals of 12 hours or less. To sum up, research should proceed in two directions: (1) refinement of observational techniques and (2) development of numerical models capable of handling the observed data.

Weather Modification

A. H. Boerma, the director general of the Food and Agricultural Organization stated in February 1973 (ref. 28):

> ...in the name of reason, can this world of the 1970's, with all its scientific process and its slowly growing sense of common purpose, go on enduring a situation in which the chances of enough

decent food for millions of human beings may simply depend on the whims of one year's weather? Is this a tolerable human condition? Emphatically not!"

Clearly, we must attach much importance to weather modification.

The design and analysis of weather-modification experiments is intimately related to the problem of predicting the weather in the absence of intervention by man. The evaluation of any attempt to modify the condition of the atmosphere depends critically on a comparison between what actually happened and what would have happened naturally. The natural state is known only to the extent that weather forecasts are accurate.

This type of cloud occuring most frequently at middle and high latitudes is the supercooled cloud or the "cold cloud," which consists of ice particles and supercooled water droplets. The cold cloud is often seeded with materials that provide ice nuclei that induce supercooled droplets to freeze. Ice crystals thus formed grow by deposition of vapor at the expense of supercooled droplets and may eventually reach sizes large enough to fall out of the cloud as precipitation.

The radio of ice particles to water droplets in a cold cloud is the parameter most amenable to man's intervention and is the foundation for most attempts at weather modification. Only a few experiments have clearly demonstrated that seeding has increased precipitation. In some experiments, there was evidence of a decrease. Apparently, the results of seeding depend critically on droplet sizes and ice-crystal properties.

Supercooled fog (cold fog) can be dissipated by seeding the fog with ice nucleants. This method is in operational use at several airports.

Warm fog (consisting of simple water droplets) may be dissipated by the use of heat, hygroscopic particles, and the down-wash of helicopters. Successful experiments have been reported with each of these techniques. The simplest method seems to be the use of heat.

There are impressive reports of reduction of damage to crops by hail. However, there are no universally recognized methods; overall, the results are ambiguous (ref. 29). Seeding methods produce different effects on different storms. Under varying circumstances, cloud seeding may result in either increased or decreased hail.

Recommended Directions for Weather Modification Research

The National Academy of Sciences has identified desirable areas for research in weather modification (ref. 25, pp 26-30). In modified form, these are:

(1) More adequate laboratory and experimental field programs are needed to study microphysical processes associated with the development of clouds, precipitation, and thunderstorm electrification.

(2) There is a need to develop numerical models to describe behavior of layer clouds, synoptic storms, orographic clouds, and severe local storms.

(3) There is a need for the standardization of instrumentation in seeding devices and testing of new seeding agents.

(4) A repository for weather modification data should be created.

(5) There is a continuing need for a comprehensive series of randomized experiments to determine effects of both artificial and natural condensation nuclei on precipitation.

(6) Experiments should be designed to evaluate effects of seeding on precipitation outside the primary area of interest.

(7) Investigations should be made to determine whether seeding techniques presently used in the study of isolated cumulus clouds and in hurricane modification can be extended to, or new techniques developed for, the amelioration of severe thunderstorms, hailstorms, and tornadoes.

(8) An expanded program is needed to provide continuous birth-to-death observations of hurricane from above, around, within, and beneath seeded and non-seeded hurricanes.

(9) A major national effort in fundamental research on hailstorms and hailstorm modification should be pursued aggressively.

(10) A comprehensive program dealing with research on warm fog and its dissipation should be undertaken.

6.4 ECONOMICS OF INFORMATION SYSTEMS

In any survey of agriculture, two related questions usually arise. One concerns technology used in the survey and the other concerns the satisfactoriness of the degree of detail or the resolution obtained. This section will discuss benefits obtainable from technology used in the Large-Area-Crop Inventory Experiment (LACIE) and will also consider the economic value of various degrees of resolution in making crop surveys.

The Role of SRS

A potential economic benefit from Landsat is the availability of timely and accurate forecasts of crop production. This subsection will examine the role of the Statistical Reporting Service (SRS) of the U.S. Department of Agriculture and the potential contributions that LACIE can make up to the U.S.

Economy. SRS makes estimates of agricultural products and costs and prices, based on nationwide multipurpose surveys throughout the year. At present, the estimates have coefficients of variation (CV) of two to six percent statewide and one to three percent nationwide. The coefficient of variation of any estimate is defined as standard error of the estimate divided by the true value. SRS has developed requirements for the number of samples to obtain a specified accuracy. The number of samples required to obtain a CV of two percent is 500 for corn, 631 for wheat, and 463 for soybeans (ref. 30, p. 4).

To estimate production of the major crops that enter the world market, 500 to 700 sample segments may be needed to obtain coefficients of variation of two percent or less. Mr. William Wigton of SRS indicated that 800 sample segments would seem to be sufficient if an estimate of the production of wheat is needed on a global basis and that 1,500 segments may be needed for estimates of other crops (ref. 30, pp 2-4).

It costs $60 to obtain information for single sample segment in the United States. If a worldwide survey were made, the cost would become $100 or more per sample segment, and the total cost would be $150,000 or more (ref. 30, p. 4). On the other hand, if LACIE techniques were used, the cost would be $1,187 per sample segment and total cost would amount to $1.78 million, according to a preliminary estimate made by NASA Ames Research Center (ref. 31, Figure 48).

The figure of $1,187 is substantially higher than that of $60. The cost of a LACIE sample segment is too high to justify the use of Landsat for a single crop in a country. However, the situation may be changed when remote sensing data from Landsat are fully utilized for many crops on a global basis.

The Role of LACIE

At present, the use of LACIE can decrease the error of estimate of area from five to two percent statewide and from two to one percent nationwide. Yield estimates for the LACIE experiments are derived from a model by means of regression analysis. Production estimates are then obtained by multiplying area estimates by corresponding yield estimates. The LACIE error of estimate of wheat production is on the order of ten percent, which compares unfavorably with the SRS error of five percent or less.

Such marginal reductions of error that LACIE can make are too costly to justify the use of Landsat. However, the real contribution that LACIE can make lies in reducing forecasting errors of the estimates of wheat production in those major wheat producing countries (Argentina, Brazil, India, China, and the Soviet Union) where substantial errors are currently being made.

The Foreign Agricultural Service (FAS) of the U.S. Department of Agriculture has calculated errors in estimated wheat production in seven countries. These values are presented in Table 6-4. P(X) in column 1 indicates that the probability that a forecast of wheat production is within ten percent of the final accepted value. A P(X) value of .64 for Argentina, for example, means that the probability that a forecast estimate is within ten percent of the final accepted value is .64. This probability corresponds to the LACIE criterion of 64/90, which means that the estimate is 90 percent accurate at harvest, 64 percent of the time.

TABLE 6-4

FORECASTING ERRORS OF THE PRODUCTION OF WHEAT AT HARVEST IN SEVEN COUNTRIES 1966-75 CROP YEARS.

Country	P(X)	1975 Production (1,000 metric tons)
Argentina	.64	8,570
Australia	.98	12,002
Brazil	.54	1,600
Canada	.89	17,078
China	na	38,700
India	.88	24,235
Soviet Union	.65	66,144
Total		1168,329

Note: P(X) is the probability that a random selection of a forecast of wheat production is within ten percent of the final accepted value.

Very few estimates have satisfied the LACIE goal of meeting a 90/90 criterion. The only country where FAS forecasts surpassed this criterion at harvest is Australia. The quality of forecasts of wheat production made just before harvest ranges from 54/90 for Brazil to 98/90 for Australia.

Improved accuracy of estimates for wheat production in foreign countries are needed throughout the growing season. LACIE is capable of making worldwide production estimates with an error of approximately ten percent. At present, no appreciable reduction of error in the production estimates of wheat is possible. However, when the problem of separating spring wheat from other small grains is resolved and sampling errors are reduced, LACIE would probably reduce errors of estimates of worldwide wheat production.

Potential Economic Benefits

Reduction of forecasting errors reduces market uncertainity and is, therefore, an economic benefit. Annual benefits from global crop information, according to Heiss (ref. 32) and Andrews (ref. 33), range between $200 and $250 million for wheat, between $50 and $100 million for corn, and between $6 and $11 million for soybeans. Significant parameters that influence estimates of benefits include the price elasticities of demand, the price elasticities of supply and the interest rate. Price elasticity is defined as the percentage change in the quantity demanded (or supplied) divided by the percentage change in the market price. The calculations by Heiss and by Andrews cited above raise several serious questions. First, the assumption that a forecast based on Landsat data of world wheat production reduces market uncertainity is unrealistic and cannot be taken for granted. Most producers are price-takers whatever the price may be, and consumers also do not have power to influence the price of grain. Even if information on estimates of grain production is available to everyone, such information has little value to most producers and consumers. Information becomes valuable only if information can affect actions of the recievers of the information. If information does not affect action, it is of no value. Thus, the assumption of pure competition in which everyone is equal in knowledge and power cannot be justified.

Second Heiss and Andrews have failed to make an absolutely essential distinction between perfect information and better information. The former eliminates uncertainity while the latter does not entirely eliminate uncertainity. Failure to make this distinction results in an overestimate of net benefits. A simple example illustrates the point.

TABLE 6-5

ESTIMATES OF ECONOMIC BENEFITS DUE TO THE REDUCTION IN ERROR OF FORECAST OF U.S. WHEAT EXPORT IN 1975 AND 1977

(Millions of Dollars)

	1975 Reduction of Errors		1977 Reduction of Errors	
	5%	10%	5%	10%
Perfect Information	$73.7	$294.8	$40.8	$163.1
Better Information with probability of 0.9	59.7	238.8	33.0	132.2

Note: Method of calculation is the same as that employed by Heiss and Andrews (ref. 10)

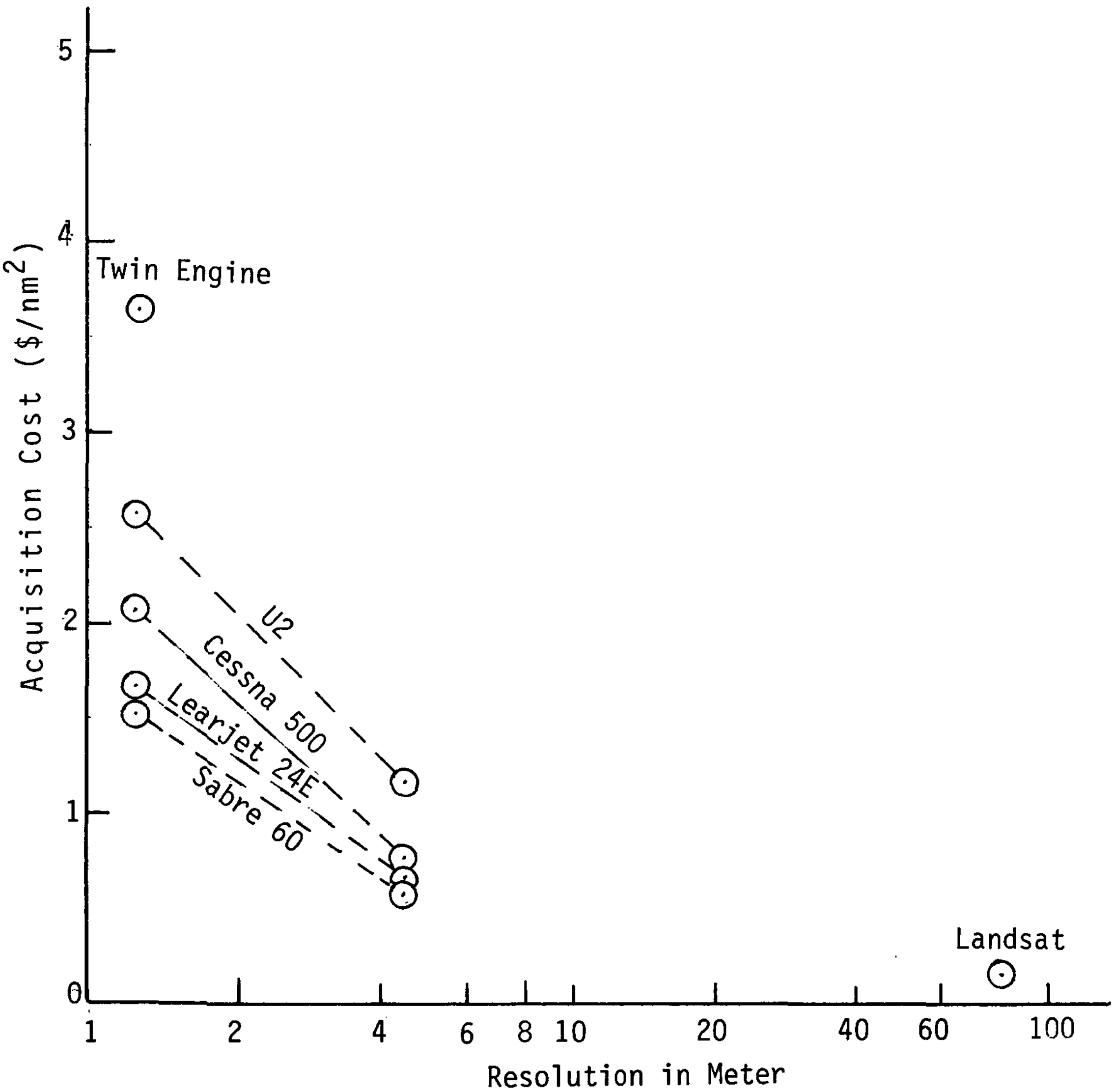

FIGURE 6-11 ACQUISITION COSTS OF REMOTE SENSING DATA BY TYPE OF AIRCRAFT

Table 6-5 compares benefits due to perfect information with those due to better information. The probability that better information on estimates of world wheat production is within ten percent of the final accepted value is 0.9. The amount of benefits varies with the quality of information and with the degree to which forecast errors are reduced. Table 6-5 also shows estimates of benefits in 1977.

The amount of benefits in 1977 is almost half that of benefits in 1975. The difference is due to the average price of wheat and the quantity of United States export of wheat.

Third, no attempt has been made by Heiss or Andrews to distinguish between aggregate benefits and individual benefits. This distinction is of vital importance to information seekers. Under imperfect competition, as opposed to perfect competition, a simple summation of individual benefits does not lead to aggregate benefits because of external diseconomies. External diseconomies are negative economic effects of one producer on another. Discharge from a chemical plant, for example, pollutes air and water and thus has negative economic effects on both producers and consumers in the surrounding area.

Economic benefits may also be examined from the perspective of cost-effectiveness when the levels of benefits are the same.

In his memorandum number 1822, August 13, 1973, the Secretary of Agriculture requested that those users of USDA information who could potentially benefit from remote sensing be identified. Apparently 110 users will be satisfied with Landsat I, II, or C at 80 meter resolution (ref. 35, pp 77-3092). This figure will increase when resolution improves to 30 meters (100 feet) in the early 1980's (ref. 35, p. 26). The remaining 80 percent of users will not be satisfied with Landsat C or D. These users need resolution better than 30 meters (100 feet).

The cost of acquiring remote sensing data is determined in part by the required resolution which, in turn, depends on certain mission or performance parameters. These performance parameters are altitude (which determines instantaneous field of view, swath, and resolution with a given camera system), cruising speed (which determines area covered per unit of time), and cost of operation (which helps determine cost per unit area).

Acquisition costs of airborne survey data are presented in Figure 6-5. The figure shows that the Sabre 60 is most cost-effective vehicle when the resolution is less than five meters (16.4 feet). It is most expensive to acquire the same data by means of twin piston engine aircraft. To obtain infrared color film positive of an area of one square mile with a resolution of 3 to 5 meters (10 to 16 feet) with Sabre 60 aircraft costs $0.57. When less than one meter resolution is required, the cost rises to $1.51, almost three times as much as that of 3 to 5 meter resolution. This indicates that the economic benefits derived from high resolution films must be almost three times as high as those from 3 to 5 meter resolution.

When resolution is in the range between 80 and 100 meters (260-330 feet), Landsat is most cost-effective (3.5¢ per sq km, 12¢ per sq n mi). However, this figure does not include the capital investment cost and includes only the cost of film processing. When Landsat is commercialized, the cost of acquiring Landsat data will increase by a substantial amount.

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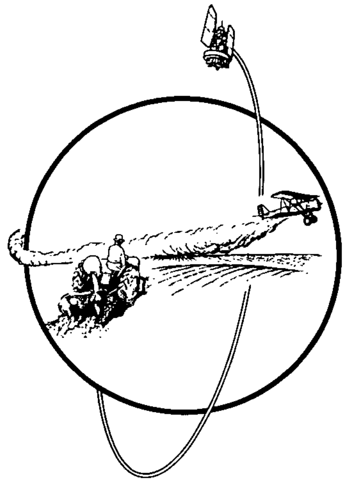

Socio-Cultural Considerations

CHAPTER 7

SOCIO-CULTURAL CONSIDERATIONS

7.1 INTRODUCTION

It is our purpose to sensitize the technical researcher, based in an advanced society, to the institutions of an underdeveloped nation that may affect or be affected by an agricultural innovation. It must be understood that socio-cultural systems not only react to an innovation, but also provide the framework for its acceptance or rejection. Today, no engineer would propose a technical change without including environmental impact as part of the equation. In Chapter 7 we will argue that the same concern must be given to social impact.

Chapter 7 is a series of four articles which outline the consequences of the introduction of technology into underdeveloped nations.

<u>The Socio-Cultural Context of Technology</u>.

In order to understand the impact of technology we must know something about the society being affected. This article outlines a typology of social systems with emphasis on those characteristics which are affected by technological change. Included is a detailed discussion of the contrast between the traditional and modern society.

<u>Demographic Considerations</u>: Coping with Reality.

Anyone who is concerned with production cannot ignore the size of the market; our market is the entire world. Past and present trends in population and the factors which influence these trends are listed. Population problems in developed and underdeveloped nations are compared. This article also introduces one of the most serious short-term effects of agricultural innovation, i.e., rural to urban migration.

<u>Obsolete People</u>: A Cost of Mechanized Agriculture.

The plight of displaced workers is a good example of a major disruption resulting from the introduction of technology into a rural society. This article is an in-depth discussion of the rural to urban migration of unemployed farm workers in the third world. A list of alternatives is included.

<u>Grain Storage</u>: An Alternative to Famine.

The last article in our chapter suggests that feeding the hungry is not simply a problem of adequate farm production. Distribution is of equal importance. In this article we justify the need for worldwide coordinated grain storage system and describe the efforts made so far.

The chapter ends with a synopsis which broadly states our intent and objectives in this chapter.

7.2 THE SOCIO-CULTURAL CONTEXT OF TECHNOLOGY

> "I have never learned to accustom myself to innovations, and I fear that above everything else, for I know full well that in making innovations, safety can in no way be preserved." Proclus, to the Roman Emperor Anastasius (ref. 1, p. 318).

Sensitivity to socio-cultural factors on the part of specialists in ag-air technology is important for at least two reasons. First, socio-cultural systems provide the framework within which all innovations are evaluated before being accepted or rejected. Second, to avoid possible catastrophes that might follow uninhibited population growth, at least some concern for the stability or equilibrium of the socio-cultural system itself is necessary. As stated by Weitz:

> Resistance to innovations may be rooted in the social structure, the pattern of leadership, religious observance, or any other non-economic consideration. In many cases, however, one finds that the proposal has not been properly explained, that it has not been made sufficiently clear that unpretentious economic improvement does not necessarily tarnish or endanger a traditional way of life, but may actually enrich it (ref. 2, p. 189).

The Evolution of Social Systems

The number of people that can be supported by a society depends on the way people organize themselves and how they obtain their living from their environment. Thirty-five thousand years ago there was one person per square mile of earth's habitable land. By 1950 there were 42 persons per square mile, and informed estimates indicate that the number will increase to 119 by the beginning of the next century (ref. 3, p. 493).

Technological innovations and increasing inputs of stored energy have helped make this growth of population possible. No less important have been a myriad of changes in the way people organize their relationships to the environment and the way in which they pattern their relationships to other human beings. The carrying capacity of the land is determined at least in part by social organization.

Changes in rates of population growth have been made possible by evolving patterns of social organization. Social organization seems to have been preceded by improved technology, increased use of non-human energy sources, and specialization in the use of labor. Although different cultures have evolved in different ways and at varied rates, there are generally agreed-upon basic types of societies that have existed through time that have also survived into the modern period. The following diagram indicates roughly the degree of overall technological advance and the level of specialization typical for each type of society or pattern of social organization.

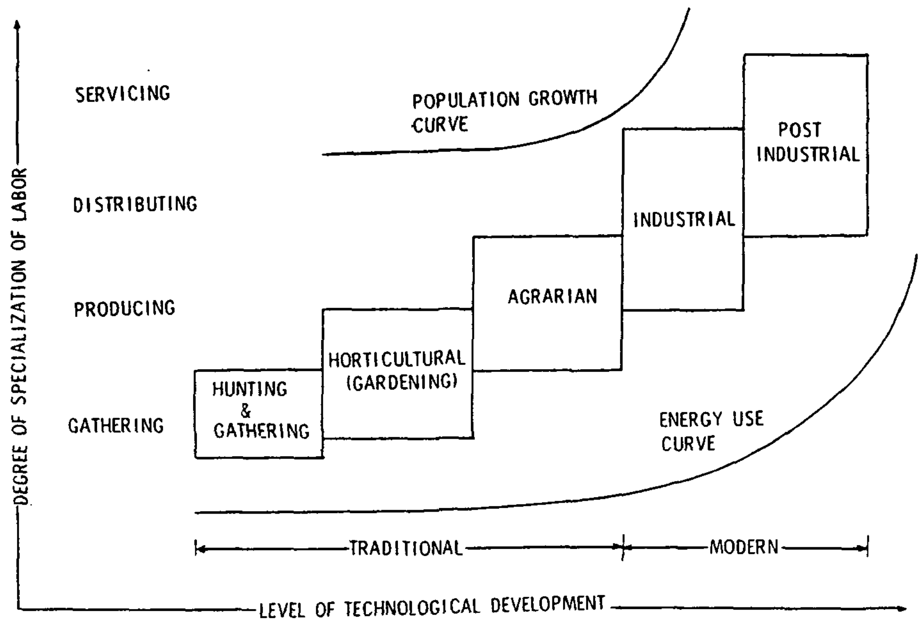

FIGURE 7-1 THE INSTITUTIONAL WEB

Of the first 915 societies recorded in the Ethnographic Atlas, there have been 151 hunting and gathering, 343 horticultural, 96 agrarian, and 104 herding or fishing (excluded from the above diagram) societies. The remaining 221 societies are hybrid, maritime, industrial, or unclassifiable. The median size of both communities and societies increase as technological development and labor specialization increase (ref. 4, p. 104).

TABLE 7-1

MEDIAN SIZE OF COMMUNITIES AND SOCIETIES: BY SOCIETAL TYPES

Types of Society	Median Size of: Communities	Median Size of: Societies
Hunting and Gathering	40	40
Simple Horticultural	95	95
Advanced Horticultural	280	5800
Agrarian	no data	over 100,000
Industrial	undetermined but: very large	very large
Fishing	60	60
Herding	55	2000

While early hunters had little more than the wooden spear, hunters and gatherers who have survived into modern times typically use the spear thrower and the bow and arrow to increase their food gathering capabilities. Early horticulturists added plant cultivation while more advanced horticulturists also use metal tools and weapons. Simple agrarian societies are characterized by plow type agriculture while the more advanced agrarian societies also manufacture iron tools and weapons. Fishing, herding, and maritime societies differ from the rest in that they are environmentally specialized. They are generally incorporated into other types of societies, and they vary both in the degree to which they make use of technology and the degree to which they use animals for transportation in work and warfare. The distinguishing characteristic of the industrial society is the use of newer sources of energy such as coal, petroleum, natural gas, hydroelectric, or nuclear power. Post industrial societies seem to be marked by larger and larger inputs of technology and energy, with fewer and fewer individuals engaged in production and more and more individuals engaged in distributing and servicing type occupations. While it is too early to indicate the distinguishing characteristic of the post industrial society, automation would certainly be important.

The evolution of societies from simple hunting and gathering to complex post industrial types seems to be accompanied by the following:

1. increasing inputs of technology and non-human energy sources.

2. increasing specialization in the use of labor.

3. decreasing numbers of individuals involved directly in production.

4. increasing outputs per worker (in both agriculture and manufacturing).

5. increased carrying capacity of the land (increased population density).

6. an increasing rate of acceleration at which the socio-cultural evolutionary process itself takes place.

The Evolution of Social Institutions

Regardless of the type of social organization, societies exist primarily to carry out certain functions that meet human needs. A human being simply cannot survive without some help from other human beings. How well the basic functions of a society are carried out determines not only the survival chances of individuals within the society but also the survival chances of the society itself. These functions have been discussed by sociologists and may be listed briefly. They are: communication, production, distribution, defense, member replacement, and social control (ref. 4, p. 28).

In the most simply structured societies most of the functions necessary for survival are carried out by all members of the group. Specialization of labor is virtually non-existent. All members participate in food getting activities. Typically men hunt animals and women gather plants provided by the natural environment. All participate in controlling deviant members of the group. All share in defending the group from attack by outsiders.

There is little observable structure in the group. Institutions as modern people know them do not exist. All of the institutional structures coalesce in a single family-like unit and all members of the group work together to meet the basic human needs necessary for survival.

On the other end of the continuum, modern post-industrial society meets basic human needs through a complex network of institutional structures. For example, fewer than three percent of the work force produces more than ninety percent of all the food and fiber consumed, another fifteen to seventeen percent produce all of the manufactured goods consumed. Fully eighty percent of the work force is freed from the basic gathering and producing functions. Specialization within the labor force is carried to the extent that more than 20,000 titles are needed to list the various occupations recorded in the United States Census. The structuring of the society is advanced to the point where specialized subsystems or institutions are clearly recognizable. Those institutions are: family, economy, political, education, religion, and class or stratification systems.

While not all inclusive, these institutional structures are readily observable in all modern societies, and to a lesser extent they are observable in agrarian and horticultural societies. They differ from one society to another as well. What seems to be a normal, rational way of meeting needs in one's own society may seem abnormal and irrational to members of some other society.

While in all societies institutions have varying degrees of influence upon one another, there are also variations from one society to another. For example, in the Soviet Union the leaders of the political institutions seem to exercise almost coercive power over leaders of other institutions, while in the United States leaders within the economic sector seem to exercise considerable influence over all institutional structures.

In most post industrial societies the family is relatively weak in terms of the influence over other institutions; in some agrarian and industrializing nations the ruling oligarchies in all of the institutions are drawn from the same families. These families constitute an aristocratic elite who perpetuate their power, generation after generation, through ownership of the land and other means of production.

Despite differences from one society to another in the power, influence, or control exercised by the various institutions, the complex web of interrelations among institutions within any given society can be at least crudely visualized by using a diagram similar to figure 7-2. (See ref. 5, p. 12 for a similar diagram).

Traditional Institutions vs Modern Societies

To illustrate the change that takes place in institutional structures as social systems advance from the traditional types (hunting and gathering, horticultural, and agrarian) to the modern types (industrial and post industrial) an attempt has been made to identify at least some of the dimensions of change that are relevant to the specialist in ag-air technology. The institutions will be discussed first for the traditional societies, then for modern societies.

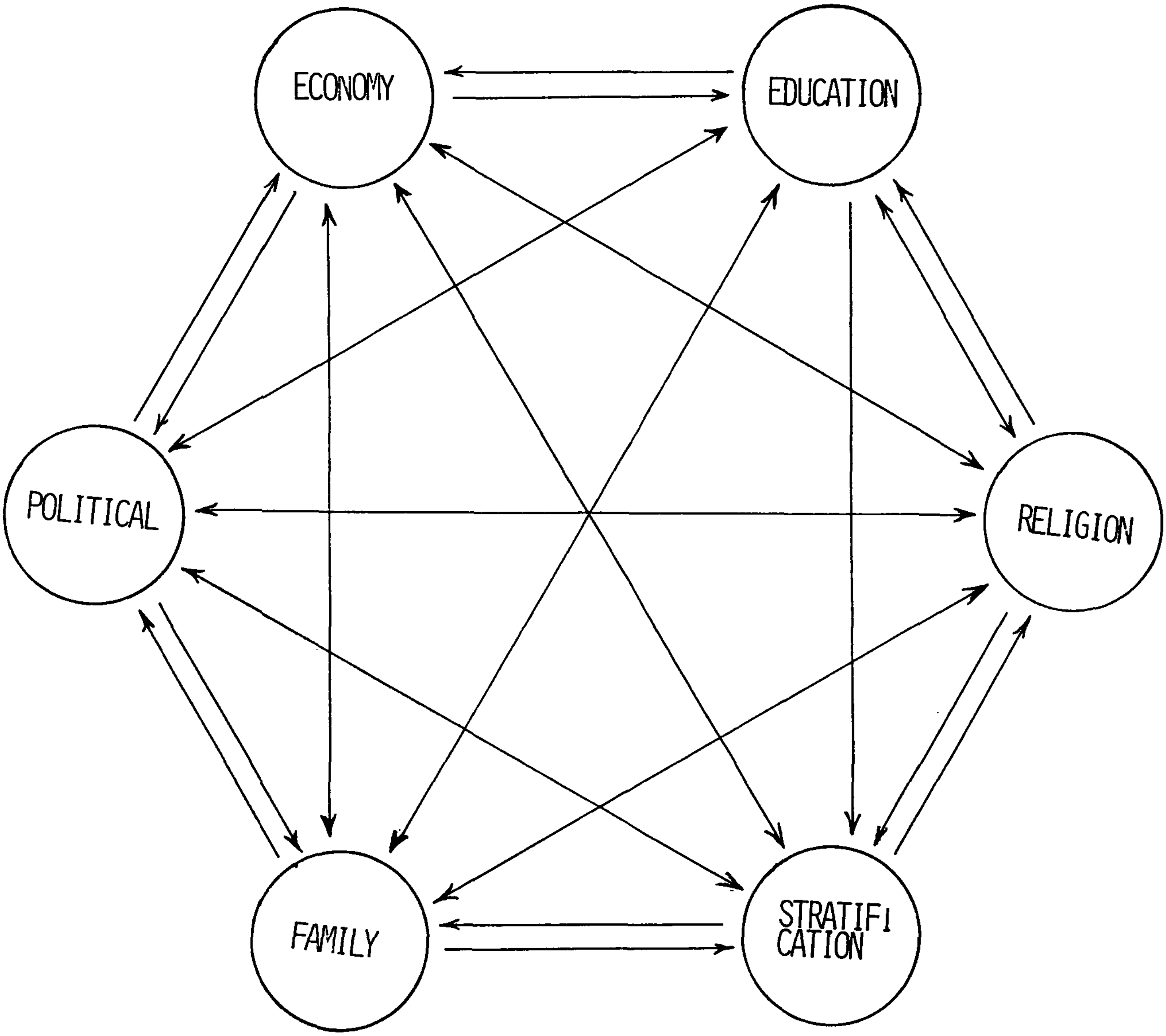

FIGURE 7-2 EVOLUTION OF SOCIETAL ORGANIZATIONS

Jonathan Turner describes the importance of the family in the traditional society.

> In sum, kinship can be considered as a central institution in traditional societies. With respect to the economy, it is intimately involved in all economic processes in that it provides the structural locus, principles of entrepreneurship, labor pool, and technology underlying these processes (ref. 5, p. 61)

In the traditional society the family may embrace the entire tribe or it may become an extended kinship system as in the agrarian type societies. Decisions are usually made in an authoritarian way by a tribal chief, or as in the case of the horticultural society by a matriarchal figure or in the agrarian society by a patriarch. In all traditional societies functions are diffuse, that is, everything that needs to be done is done by the family. Even in agrarian societies families have great influence over other societal institutions. The family provides labor resources, and also provides for the welfare of individuals not integrated into the economic life of the community.

Economic decision making often appears to be non-rational in the traditional society. Much trade is carried on through a barter system rather than through a system of money exchange. Credit is difficult to obtain because there is often no way to enforce repayment of debts. Where central markets exist bargaining is often a salient feature. Wages are determined not only by the market value of the labor performed, but by the needs of the person performing the labor and by the prestige he holds in the community. Economic considerations are often regarded as less important than family, religious, or political obligations.

In more simple societies there is insufficient economic surplus to support an elaborate political structure. In agrarian societies power is often concentrated in the hands of a small number of families who own large tracts of land. In the absence of written or codified law, customs and mores are often powerful determinants of behavior and are enforced by virtually the entire community.

Education in traditional societies is often oriented toward expressive artistic goals rather than rational scientifically determined goals. Children often learn by doing, by practicing the roles they will be expected to perform as adults. Those who receive advanced education are frequently trained for non-economic statuses such as those necessary for becoming a member of the religious or political elites. Education is typically conservative or elitist in its orientation.

Religion in traditional societies often tends to reinforce crucial economic norms. Generally, most people within a society will have beliefs that are fairly similar to those of other members of society. Deviance is not tolerated. Individuals are not encouraged to question traditional practices and this sacred quality pervades virtually every aspect of social life. The force of religion in traditional societies is often very strong and can often serve as a focal point for resistance to change.

Stratification systems in traditional societies tend to be fairly rigid. Frequently, one's status throughout life is determined by the status of one's family. Movement to a higher or lower status is virtually impossible, although in some agrarian societies there are limited opportunites for upward mobility. Very rigid systems of stratification are usually referred to as castes or estates.

The point of departure for most of the specialists developing ag-air technology is the modern post industrial society. It differs from the traditional society in two essential features: 1) the family serves less and less as a focal point for all other activities, and 2) highly structured institutions have emerged to perform functions once performed by the family. A brief look at some of the salient features of the institutions of modern society may help the ag-air specialist become more aware of some of the potential trouble points that will be encountered when transferring complex technology to traditional societies.

The family in modern societies typically consists of a man, a woman, and their offspring. Aunts, uncles, grandparents and assorted other relatives are missing from the typical modern household. Decision making is egalitarian in nature. The family's functions are typically limited to procreation and to training of the young. The family exercises little or no control over other institutions, but in contrast to traditional societies finds itself very much dependent on outside institutions for a wide array of services, such as economic assistance, help in educating the children, religious services, and so forth. Traditional societies lack these institutional supports.

The economic system in the modern society is based on the notion that decisions are made by rational beings who tend to maximize their options in achieving a wide array of personal goals. The individual's place in the economic structure is based on merit. The rewards one receives are based on the degree of skill one has to offer and the degree to which one's job is regarded as important in maintaining the public welfare. Goods are sold in a market place to anyone willing to pay the price. Credit is widely available. For many commodities, value is known, and prices are fixed. Leaders in the economic structure exercise a high degree of control over leaders of other institutions.

The political institution in the modern society is based on written law which is ideally applied in the same way to all individuals and corporate structures. The political institution provides for the welfare of those who have no useful place in the economy. This is done through legitimized power to appropriate and redistribute economic supplies. Political power tends to be less concentrated in the modern society than it is in the traditional society.

In the society the educational institution is one of the most powerful instuments of social change. The orientation tends to be rational and scientific and it is the principal institutional source of new technology. Education is directed toward the masses and thus tends to be egalitarian rather than conservative and elitist. Educational institutions are the principal source of labor and the placement of labor in the economy is an important function. Children are not taught by demonstration of activities. They are taught about activities.

Religion and religious attitudes in the modern society have lost ground in terms of influence upon the society. All things are open to question. Reality is perceived with the mind rather than with the senses. The rational will predominates and the prevailing attitude is that anything can be changed. There is a high level of tolerance toward deviance in terms of both belief and behavior. The power of religion over other institutions is low, and religion is regarded by most individuals as a weak and passive force in the society. The principal function of religion in modern society is to alleviate anxieties and tensions of individuals.

Stratification in modern society is also different from that of traditional society. One's position in the society can be changed. It is based primarily on skill or ability in performance of one's occupational role. Occupation is the best single indicator of one's position in the society, and the most widely accepted avenue of upward mobility is one's performance in the educational system. The open class system is characteristic of the modern society.

<u>Technological Change and Socio-Cultural Evolution</u>

While it is not likely that detailed socio-cultural impact studies will be undertaken each time a new innovation in ag-air technology is introduced into a different socio-cultural framework, it may be appropriate to give some attention to the following considerations:

1. Who, within the receiving culture will resist the new technology and who will be receptive toward it? Why?

2. What will be the short and long range consequences of the innovation? Will it permit the society to move to a more productive, more desirable level, or will the effect be retrogressive, dysfunctional, and disruptive?

C. M. Halpern states that:

> ...the revolution of modernization involves transformation - the transformation of all systems by which man organizes his society, that is, his political, social, economic, intellectual, religious, and psychological systems... The revolution of modernization is the first revolution of mankind to set a new price upon stability in any system of society - namely, it requires an enduring capacity to generate and absorb persistent transformation (ref. 6, p. 41).

Rodgers and Shoemaker demonstrate what can happen when a well meaning but misguided agent of change introduces a new element into a culture.

> The introduction of the steel ax among Australian aborigines brought many dysfunctional and indirect consequences, including breakdown of the family structure, the emergence of prostitution, and "misuse" of the innovation itself. The story of the steel ax illustrates three intrinsic elements of an innovation: (1) form, which is the directly observable physical appearance and substance of an innovation, (2) function, which is the contribution made by the innovation to the way of life of members of the social system, and (3) meaning, which is the subjective and frequently subconscious perception of the innovation by members of the social system. Change agents can more easily anticipate the form and function of an innovation for their clients than its meaning (ref. 1, p. 344).

People in the United States, beginning with a large cultural inventory imported from virtually every part of the world have taken more than three and one-half centuries to assemble the complex social structure that permits U.S. agriculture to function with a high level of efficiency and productivity. Despite the very slow rate of change and growth, strain within the socio-cultural framework is evident to even the most casual observer.

High unemployment rates among minorities, high rates of crime, high rates of family dissolution, and uncontrolled environmental pollution are among the more obvious symptoms of stress in modern society. This stress is brought about by the fact that social institutions evolve very slowly. Changes in social institutions have not kept up with changes in technology. Changes in technology seem to be welcomed. Changes in social institutions, particularly if planned, are resisted.

Third world nations seeking rapid solutions to agricultural problems through purchase of advanced technology and capital goods may be setting into motion very rapid changes that in the long run may prove catastrophic. The lengthened life span made possible by modern sanitation and western style medical practices has not proved to be an unmixed blessing. Rapid increases in population and subsequent food shortages have brought about a great deal of suffering that was unintended. What modern nations have failed to achieve in centuries can hardly be achieved by third world nations in decades.

Attention to long range effects of new technology should not be ignored. It may be possible to double the world's population through the increased food made available by the technology of the advanced nations. However, if the fuel to propel the machinery that makes food so widely available is priced out of the market for the third world nations the long range consequences will most certainly be catastrophic. War, famine, pestilance, or disease may become a solution imposed by nature.

It could perhaps be argued that we have a moral obligation to sell food or food producing technology only to those nations who develop programs to control population growth. The preservation of some sort of socio-cultural stability in third world nations may, in the long run, prove to be of greater importance than the more immediate problem of providing food for the world's hungry people.

Eisenstadt states the dilemma clearly.

> The very steady economic expansion tended often to worsen the lot of some deprived lower groups and strata and to minimize their effective accessibility to the new framework. Moreover, intensive social and economic development often dislocated various groups, especially lower- and middle-class ones, and make them feel alienated from the central framework....(ref. 6, p. 64).

Rodgers and Shoemaker seem to feel that an ideal rate of change can be achieved, however:

> In determining an ideal rate of change, the concept of equilibrium must be considered. Stable equilibrium occurs when there is almost no change in the structure or functioning of the social system. Dynamic equilibrium occurs when the rate of change in a social system is commensurate with the system's ability to cope with it. Disequilibrium occurs when the rate of change is too rapid to permit the social system to adjust. Change agents generally wish to achieve a rate of change which leads to dynamic equilibrium, somewhere short of disequilibrium (ref. 1, p. 344).

The range of socio-cultural problems that may be encountered in developing new technologies to solve the food problem of the world's burgeoning populations is vast. The following pages focus on several that seem important at this time.

7.3 DEMOGRAPHIC CONSIDERATIONS

The rate of human world population growth is about two percent. At this rate the world population will double every 35 years. In underdeveloped countries the doubling time is less than 25 years. This situation is unique. We have the highest growth rate in human history from the greatest population base (4 billion). This is because medical technology has reduced the death rates, and as yet has made less change in the high fertility rates. It is obvious that this rapid population growth cannot continue very long. The question is by what means will the population level off? There are three possibilities, a high death rate, a low birth rate, or some combination of the two. The birth rate must be brought into balance with the death rate or mankind will breed itself into oblivion (ref. 7).

Demographic Evolution

During this entire history of mankind the growth rate has been very low, certainly less than 0.1% per year. At the time when agriculture developed, about 8000 BC, the population was estimated at from 5 million to 10 million. This estimate is based upon the maximum number people that the social and technological development of primitive tribes would support together with the land area necessary to support hunting and food gathering cultures, (Midden heaps have also been of considerable value in estimating prehistoric populations). The increase in food supply by the initiation of agriculture, and the domestication of animals made the great increases of human beings possible. At the

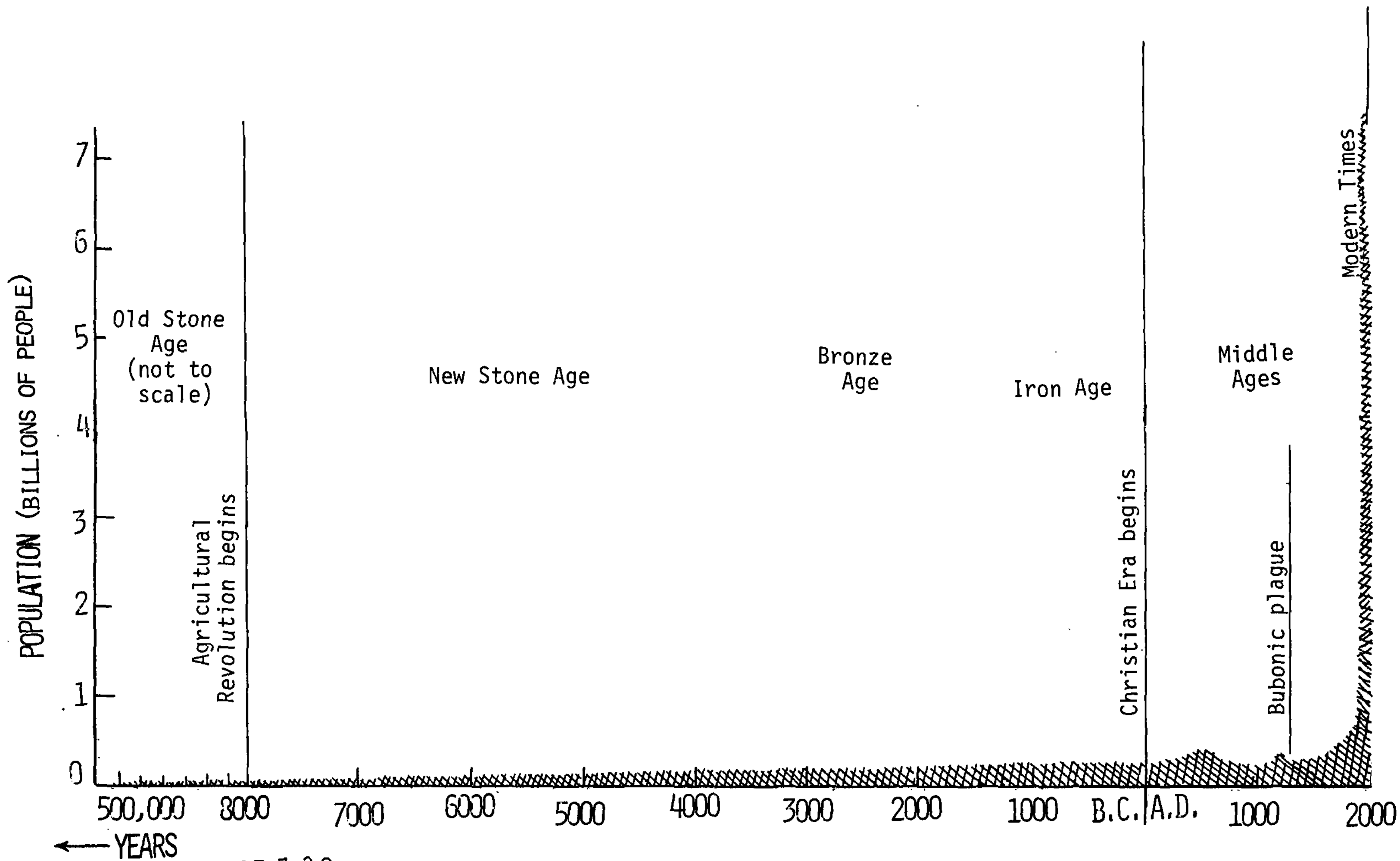

FIGURE 7-3 GROWTH OF HUMAN NUMBERS FOR THE PAST ONE-HALF MILLION YEARS. IF OLD STONE AGE WERE IN SCALE, ITS BASE LINE WOULD EXTEND ABOUT 18 FEET TO THE LEFT.

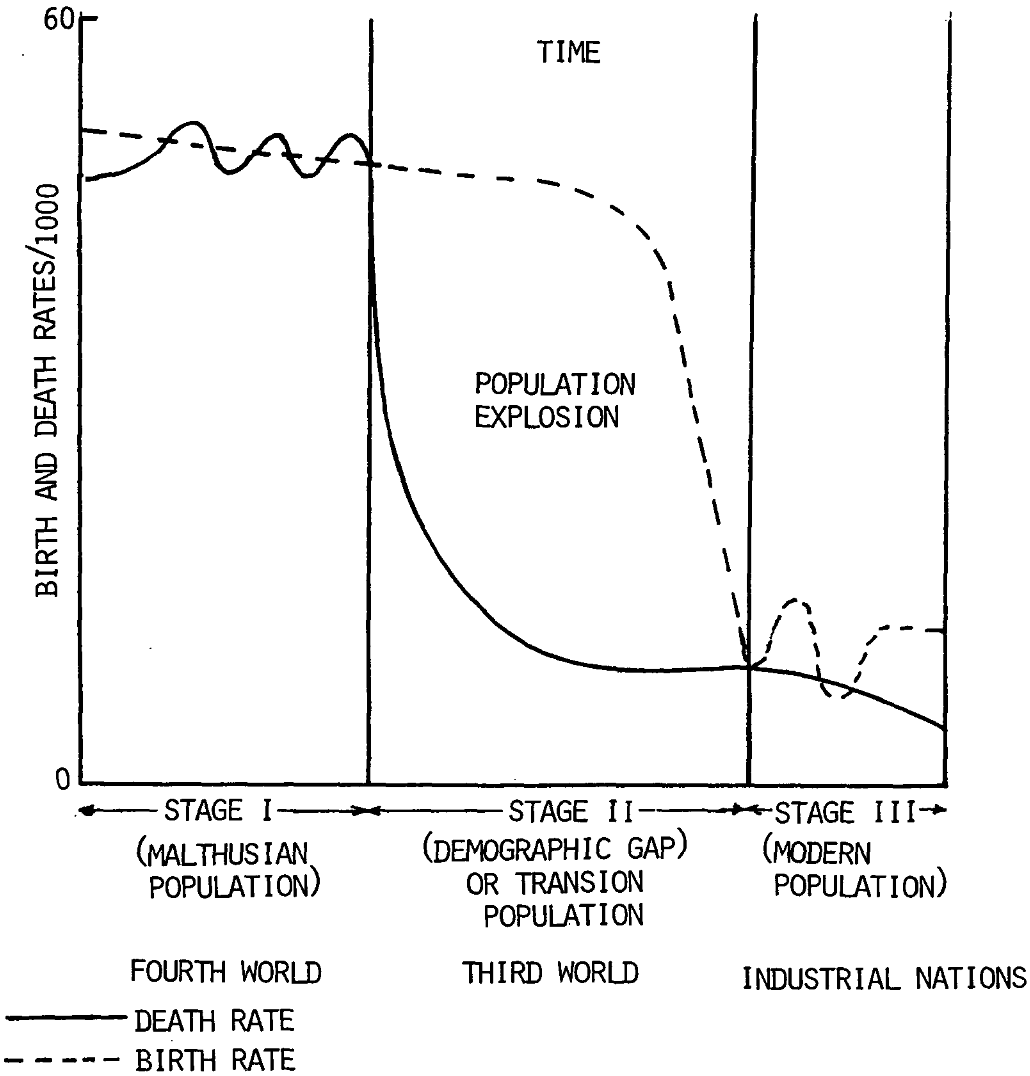

FIGURE 7-4 THE DEMOGRAPHIC TRANSITION

beginning of the Christian era, 1 AD, the population is estimated at about 300 million. The annual rate of increase was .36 per 1,000 population. From 1 AD to 1750 the population increased from about 300 million to some 800 million (ref. 8). About this time the accelerated population increase began. Smallpox vaccination, better nutrition, personal hygiene, and lessening of the black plague were factors in the sudden increase. The annual growth rate from 1 AD to 1750 was .56 per 1,000 population. From 1750 to 1800 the rate of increase went up to 4.4 per 1,000 population. Thus in 1800 the world population had jumped to 1 billion. It continued to climb at an accelerating rate reaching 1.3 billion in 1850, and 1.7 billion in 1900. The rate of increase in 1900 was 5.4 per 1,000 population. The population reached 2 billion in 1930 and 2.5 billion in 1950, at a growth rate of 7.9 per 1,000 population. From 1950 to 1975 the growth rate more than doubled to 17.1 per 1,000 and the present world population in 1977 is over 4 billion. There is every expectation that even with a birth rate reduction to replacement level by the end of this century, which hardly seems possible, the world population would reach 8.2 billion.

Developed vs Underdeveloped Nations

The birth rate in the underdeveloped countries remains high, averaging almost 3% in annual increase (ref. 9). Many of underdeveloped African countries, Pakistan, and Bangladesh are increasing three times as fast as the developed countries. The birth rate in the underdeveloped countries is about 39 per 1,000 population while the death rates have been reduced to 14 per 1,000 population. Compare this to an average birth rate of 17 per 1,000 population and a death rate 9 per 1,000 population in the developed countries. It is evident that 90% of the population increase is taking place in the underdeveloped countries. This rapid increase is sometimes referred to as the "population explosion" (See figure 7.3).

The population is also increasing in the U.S. both because of the number of legal and illegal immigrants and the age structure of the population. Even if zero growth rate reproduction is achieved, the U.S. population will increase 49 percent in the next 50 years.

The Population Problem

Human population must be considered not only with reference to the food supply, but also with reference to nutrition and health, social organization, stress on the environment, industrial development, and the availability of energy. There has been a controversy in the last few years about how to begin to deal with the population problem. The industrial countries have taken the view that improvement of the individual standard of living is dependent on the food and resources available per capita. Therefore, according to this logic, the way to improve the individual's standard of living is to limit population growth while increasing agricultural yields and introducing transportation systems, communication systems and industrial development. Thus the reduction of fertility rates will greatly enhance social and economic progress. However, at the United Nations World Population Conference in 1974, a different approach by the underdeveloped countries was emphasized. This approach is that: Population growth is not the real problem. The real problem is to feed the hungry, introduce industrialization, redistribute income, improve the status of women and banish social injustice. Then the population will level off of its own accord and the problem will be solved (See figure 7.4 below). There is some historical validation for this concept. The history of most of the developed countries has shown this pattern, and especially the cases of South Korea and Taiwan in 1970's

Modern Migrations

Historically man has been able to handle his modest increases in births over deaths, and to increase his food supply by moving into new territory. Primitive man is thought to have originated in Africa and then moved to Europe, Asia, America and Australia. Paleolithic man has achieved a wider distribution than any other terrestrial species. This inherent tendency of man to move out into new territory continued as he became organized into tribes. The tribes with superior organization and techniques could invade and use territory occupied by other tribes. The social and organizational traits for the agressive tribes were thus preserved. In modern times these human migrations have continued as rural people give up trying to make a living from the land and move into the city. Also masses from the underdeveloped countries are emigrating to the developed countries.

The country to the city migration has been going on since men built cities. In Athens, at the time of Pericles, half the population were migrants from the country side (ref. 10). A variant of this type of migration occurs in colonization. From ancient empires to the 19th century, empires attempted to extend their control by planting colonies away from the homeland. The corporation and the U.S. military seems to be following this pattern. There is hardly a major city outside the communist countries which does not have its colony of American business and military families. The most obvious population trend in the United States is the continuing rural to urban migration (ref. 11). More than 75% of our population is urban at the present time (ref. 12). An increase in manufacturing, service jobs, and transportation have absorbed displaced farm labor. But the increasing air and water pollution, increasing slum areas, and deterioration of the school systems have been blamed on the inability of our cities to absorb all the migrants. However, rapid urbanization is also occurring in the underdeveloped countries. In South America there has been a flood of peasants into urban areas without increased employment. Thus huge shanty-towns have developed about the cities. Africa has the same problem with hundreds of thousands migrating to the cities and no increase in employment opportunities. Nairobi has a population of over 500,000 and is growing at a rate of seven percent per year; Accra is growing at eight percent a year; Abidjan is growing at ten percent a year and Lagos, capital of Nigeria, is growing at 14 percent a year. There is no solution to this problem at the present time. An increase in food production is urgently necessary if the fabric of civilization is to hold together.

7.4 OBSOLETE PEOPLE: A COST OF MECHANIZED AGRICULTURE

Traditional societies engage a large number of people in agriculture. In hunting and gathering and horticultural societies virtually all persons devote most of their time to gathering and producing food. In agrarian societies as many as 95 percent of the residents are rural, and most are engaged in agricultural activities. In contrast, a modern society like the United States produces ninety percent of its food and fiber with fewer than three percent of the people employed directly in agriculture (ref. 14, p. 69).

The Modern Experience

In Western Europe and the United States the transition from agrarian to modern type agriculture occurred over a period of several centuries. As agriculture became highly mechanized, and as the volume of food produced by each agricultural worker increased, persons not needed on the farm migrated to towns and cities. Some found jobs producing the machines and commodities that made higher rates of production possible. Others entered factories where goods were produced that permitted a higher standard of living for all segments of the society. In recent years more and more people have moved into distributive and service occupations. With rare exceptions, an efficient and productive system of agriculture providing a generous surplus of food has been a basic ingredient of the industrializing process.

Generally speaking, the transition from agrarian to modern agriculture was accomplished without unmanageable stress to any specific segment of the population. Even though most rural-urban migrants entered the urban labor market at the lowest level, higher wages, more comfortable housing, shorter working hours, improved services, and the hope of better life chances for themselves and their children made the move acceptable.

The rural-urban migration is an accomplished fact in the industrialized nations, having slowed to 15,000-20,000 persons per year in the United States (ref. 15, p. 249). Nevertheless, in very recent years the United States has experienced an overall unemployemnt rate of seven to nine percent (ref. 14, p. 68). Among minorities, nationwide unemployment rates have approached twenty percent (ref. 14, p. 69). Generally, unemployment is most severe among persons who are poorly educated and who lack skills that enable them to perform useful work for pay. Groh summarizes the plight of the black rural-urban migrant forced to leave the farms yet lacking the necessary skills for an industrial occupation:

> ...the passing of even a wretched system can be a disastrous event to those who are ill-prepared for transition. So it has been for most farm blacks. Once they were exploited but functional. Now they are simply obsolete...(ref. 16, p. 65).

Rural whites also suffered from changing farm patterns. Of the 12.5 million rural poor, nearly nine million are white. The question is: What can the nation do for obsolete people who can find no niche in the economy?

The Traditional Experience

While modern nations have unemployment problems of recognizable proportions, third world nations are facing problems that are much more serious both in terms of magnitude and variety. First, to feed their large populations, these nations are increasingly turning to mechanized high-energy agricultural processes. Yet, extremely high rates of rural-urban migration, are further increased each time a new machine or innovation reduces the demand for labor. This migration coupled with a continuing high fecundity rate among the urban poor, has created large cities that lack sewers, water, housing, schools, services, jobs, and the political and economic institutions to create them. The problem is compounded by the fact that the speed at which the process is occurring is much greater than it was in the industrialized parts of the world. Also, developing nations employing mechanized agricultural techniques must import technology, machines, fuels and fertilizers needed to increase productivity. The urban population produces few goods marketable in the worldwide economy, the exports are often basic food products that are needed at home to feed the burgeoning urban population. The problem is well documented and it is being faced in virtually every part of the world. Mechanization of agriculture is forcing the peasant to leave rural areas for the city and the city has no means of providing for his needs.

Implications for the Future

The rural-urban migration phenomena is, indeed, of worldwide proportion affecting both modern and traditional nations alike. In Australia rural population has decreased from 31.1 percent in 1947 to only 14.7 percent in 1976 (ref. 17, p. 3). Africa is urbanizing at even faster rates; statistics show a 41 fold growth in a century compared with a nine fold growth in Asia and only a doubling in Europe (ref. 18, p. 5). In India, Ashish Bose suggested that even given another 20 years, industry will not be able to keep up with the expanding urban population (ref. 19, p. 105). Bussey, speaking of papers read at the United Nations Sponsored World Population Conference, said:

> In summing up the contents of thirty-three papers presented by representative of nations from all parts of the world, the moderator concluded that one of their impressive overall characteristics was the similarity of the picture they presented. "The rural-urban movement is one that transcends political boundaries, stages of economic development and political ideology rapid urbanization is a trend which prevails throughout the world and is likely to continue" (ref. 20, p. 2).

Urbanization has created serious social-psychological problems, especially for the non-westernized people. Simic, in terms that are somewhat dramatic, noted that:

> For traditional societies, modernization signifies not merely an increase in magnitude, but also a change in the very nature of human relationships...the pressure of modernization may totally

> destroy preindustrial life styles, often bring about psychological and social disintegration of peoples unable to come to terms with new conditions of life (ref. 21, p. 9).

Wherever one looks in the world of non-industrialized nations a similar picture emerges. Improvements in agriculture reduce the need for labor. The surplus people migrate to the cities, where they frequently live under substandard conditions and search for jobs that simply do not exist. It is not as surprising that urban revolts occasionally occur, as it is that they do not occur on a more regular basis. Havens and Flynn, discussing the problem in Columbia, said:

> Our analysis concludes, then, that three necessary conditions exist for structural change (revolution) in Columbia. These three necessary conditions, that we feel occur in chronological order, are rapid rates of urbanization, widespread feeling of relative deprivation, and a severe level of anomie...However... there is no organized activity to draw upon this potential for structural change (revolution)...Columbia is not a country where widespread class consciousness is prevalent...there does not exist a total revolutionary class in Columbia (ref. 22, p. 240).

While the worldwide scene reveals urban suffering that is stark and unrelieved, the rural setting likewise seems often unimproved. Frank Cancian, reporting on a ten-year study of government efforts to improve agriculture among the Mayan peasant farmers in Southern Mexico said about his studies: "...they show that some people are better off, but not that people on the whole are better off" (ref. 23, p. 129). Case studies illustrating similar conditions or urban unemployment and rural underemployment exist for virtually every region of the world.

The question is the same as that raised for the industrialized nations. What can be done for the obsolete people who have no niche in the economy? It should be obvious that unthinking widespread adoption of improved ag-air technology will accelerate the release of labor from agriculture and compound the problems associated with rural-urban migration. It does not seem inappropriate that the ag-air specialists should be aware of the several courses of action that may be pursued. Briefly the alternatives are as follows:

1. The problem can be ignored. This alternative is not only morally questionable, but it is likely to lead to crises of even greater magnitude in years to come.

2. Allow the urban ghettos to continue their unabated growth, but make heroic efforts to provide food and services for the poor. The questions remaining are: a) who pays for it and b) will it lead to widespread political unrest, violence, and war?

3. Create cities of moderate size in rural areas that relieve the pressures on the larger cities. This solution has been tried with at least some success in Netherlands, Mexico, and Israel (ref. 20).

India has also had some favorable results in creating new towns to manufacture and distribute the simpler consumer goods required in the countryside (ref. 24, p. 30). The same process seems to be occurring in the United States without intervention by the national government (ref. 15, pp 243 & 280).

4. Mechanize selectively. Combine techniques that increase productivity with techniques that are labor intensive. Experiences in India indicate that small intensively worked units are more productive than larger units farmed with extensive techniques.

Furthermore, machinery that has been employed in the past to displace labor can be turned toward labor-intensive uses. Ag-air, for example, can produce three or four crops on land normally used for a single crop, thus increasing the demand for rural labor (ref. 24, p. 49).

The problem of obsolete people is real and it has the potential of reaching proportions that will be catastrophic in nature. Much thought and appropriate planning are recommended.

7.5 GRAIN STORAGE: AN ALTERNATIVE TO FAMINE

Had the modern world been designed and maintained by a systems engineer, with man's convenience as a design criterion, we would have the right amount of food available at the right time and place. Unfortunately, the World Food and Nutrition Study, recently published by the National Research Council of the National Academy of Sciences points out that food is not available in the right amounts at the right times and places.

> Sharp fluctuations in food supplies and prices have seriously aggravated the problems of hunger and malnutrition in many parts of the world. Much of the instability arises from acts of nature, such as extreme weather variations or heavy infestations of pests and diseases that destroy crops and animals (ref. 25, p. 35).

The study goes on to say that the world food supply is also affected by "political destabilizing events" (ref. 25, p. 35).

The Problem

Fluctuations in world food supplies can be attributed in large measure to the interaction of four variables: weather, disease, inadequate storage facilities, and economic considerations. Even though the causes of these fluctuations are complex and interactive in nature they can be identified, explained and in gross terms, quantified. Rough estimates of these fluctuations are presented in Table 7-2.

Agriculture can be viewed as a system for converting energy into consumable food supplies. Much of the energy involved in food production comes directly from the sun, and sunlight is not equally distributed in all parts of the world. In tropical regions growing seasons may extend throughout the year while in temperate zones food crops may grow only four to six months of the year. Large human populations are concentrated in the mid latitudes where growing seasons are short and people have learned to survive the winter only by producing surpluses that can be stored and eaten as needed.

In addition to seasonal variations, there are variations due to weather. Over large climatic regions variations in weather may produce annual fluctuations in crop yields as great as ten percent above or below average. This is a conservative estimate. Large countries like the Soviet Union or the United States include many climatic regions and it is unlikely that a single bad season could reduce food supplies to the famine level. Still the 1975 drought in the Soviet Union caused a 15 percent reduction in expected grain output (ref. 26, p. 3). However, in small countries, or countries dependent on meteorological phenomena such as monsoons, a single bad season can cause almost total crop failure. Our estimate of ten percent fluctuation due to weather used in Table 7-2 is modest.

Plant diseases or pest infestations also pose a threat to world food supplies. In the United States, the 1970-71 corn blight destroyed 15 percent of the total crop (ref. 27, p. 13). In the four leading corn producing states in the south (North Carolina, Tennessee, Kentucky, and Georgia) the losses exceeded 30 percent. The ten percent figure used in Table 7-2 is therefore conservative.

Closely related to these losses are those that occur due to disease, pest infestation, and rodent activity after crops are placed in storage. In India, for example, losses due to rodent activity alone may amount to 40 percent of grain stored (ref. 28, p. 3). It is estimated that grain stored must be increased by 25 percent to compensate for losses incurred after crops are harvested. Our figure of five percent of production to compensate for losses while in storage is in no way overstated.

While the economic processes that influence wheat production are extremely complex, they operate approximately as follows:

1. Surplus production of wheat leads to large amounts being placed in storage.

2. Large reserves in storage drive prices down in both domestic and world markets.

3. Low prices have a negative effect on the farmer's incentive, so he reduces the number of acres devoted to wheat.

4. Low acreages supposedly reduce yields which drive prices up which in turn leads back to the starting point where the cyle begins once more.

For example, prior to 1972, 60 million acres were withdrawn from grain production in the United States (ref. 29). Then came the world food shortage of 1973-74, aggravated by a shortage of fossil fuels. The Russians bought most of the grains available in storage and drove up the price of wheat to $5.52 per bushel. Stocks in storage were reduced to a twenty-five year low. The high wheat price and empty storage facilities induced American farmers to increase wheat production. The years 1975, 1976, and 1977 were exceptionally good for favorable grain harvests throughout the world. Grain reserves have now reached an all time high, and wheat prices have fallen to $2.35 per bushel. Corn prices have likewise fallen to $2.04 per bushel (ref. 30, p. 27).

The up and down swings in the amounts of food available in the world market can best be described as a boom-bust or feast-famine cycle. There is either too much or too little. Fluctuations due to the vagaries of the market place amount to as much as 20 percent of normal production.

The following table summarizes our estimates of fluctuations in grain production attributable to weather, disease, inadequate storage facilities, and economic considerations. In years when most of the factors fluctuate in a positive direction a glut in the market occurs. On the other hand, in years when most factors fluctuate in a negative direction the result is famine.

TABLE 7-2

WORLD FOOD PRODUCTION FLUCTUATIONS

Causes	Variations in ± %
Weather	10
Diseases	10
Storage	5
Economic	20
Total	45%

Compounding the problem is the fact that storage facilities are not located where they are needed. From Table 7-3 it can be determined that although the developed nations in the security agreement of the Food and Agricultural Organization of the United Nations (FAO) have less than half the population of the developing nations in the agreement, they have nearly 90 percent of the combined storage capacity. Of the 69 million tons held by the developing nations 21 million tons are stored in a single country (Argentina) leaving only 48 million tons for all other developing countries. A similar situation exists for nations not belonging to the security agreement. Brazil owns 68 million tons or nearly 80 percent of the capacity of these nations. The entire storage capacity of non-FAO nations is held by one country (Soviet Union). Of those nations not reporting to FAO virtually no information is available. Included in this category is China. However one looks at the problem, storage capacity is not adequate in developing nations where population is greatest and needs most acute.

The Solution

Since weather, diseases, and economic factors are only partially, and in most cases belatedly, controllable by man, the most reasonable approach to leveling out the boom-bust and feast-famine cycle is through improvement of world storage facilities. Our figures in Table 7-2 based on analysis of fluctuation in crop yields indicate that worldwide storage capacity should be equivalent to 45% of annual world grain harvests.

Approaching the problem from a different perspective the Food and Agricultural Organization of the United Nations reached an almost identical solution. It has been observed that it takes approximately six months from the time famine is reported until grains can be moved from an area of surplus to an area of need. Therefore, the FAO recommends that storage capacity equivalent to six months consumption be built in developing nations (ref. 31, p. 3).

Since there is no conceivable way of overcoming inadequacies in transportation networks in developing countries in the forseeable future, it is important that storage facilities be distributed throughout the world, particularly in developing countries with large populations to feed. Table 7-3 column 5 indicates the needed capacities.

While ag-air techniques can contribute to increased food supplies on a worldwide basis, it is conceivable that increased supplies will only accentuate the fluctuations in harvest without an accompanying effort to offset the possibility of famine during years of poor harvests. Storage facilities located in developing nations can be singularly effective in attenuating the currently existing feast-famine cycle by leveling out extremes in the fluctuations and reducing ups and downs in prices. Improved monitoring of worldwide expected harvests through remote sensing is also expected to be an effective tool in reducing unexpected crop losses.

The World Food and Nutrition Study has expressed the need for an information system to keep abreast of world food needs.

> Total Information Systems Design - A total information system for any given subject, such as crop production, involves many components. A framework is needed to specify appropriate inputs by disciplines. Ways must be found to deal with equipment, procedures, survey and statistical design problems. Total systems design also must consider putting together more than one system, possibly across subjects, or across geographic areas. Research at any one time can tackle only the most feasible and urgent parts, but total systems design research looks at the whole. Only this type of research can handle adequately feedback mechanisms, interactive system linkages, collaboration with related areas of interest such as agriculture and space and the development of information theory.....Research is recommended

TABLE 7-3

WORLD STORAGE SYSTEM

	Population (millions)	Yearly per capita consumption (kilograms)	Total consumption for 1 year (millions of metric tons)	Existing storage capacity (millions of metric tons)	Needed storage capacity (millions of metric tons)
1) FAO reporting nations (all)	2784	309	860	929	430
2) U.N. Members of Security Agreement	2191	332	728	563	364
3) Developing Nations in Security Agreement	1500	220	330	69	165
4) Developed nations in Security Agreement	691	576	398	494	199
5) FAO Members not in Security Agreement	347	220	76	87	38
6) Non-member (FAO)	257	788	202	280	101
7) Nations not reporting to FAO	1105	---	---	---	---

*Table 7-3, above, illustrates the world grain storage problem. The data are taken from several different sources and are not from the same year. The population data are from a 1977 almanac (ref. 32, p. 269). Figures on storage capacity are estimates of 1980 capacity reported to FAO (Food and Agricultural Organization) by the individual countries (ref. 31, pp 1-19) The per capita consumption (per year) data are for 1970 and were taken from a National Academy of Sciences report (ref. 25, p. 157). The rows of this chart follow a breakdown used by FAO.

to: Develop a conceptual framework to guide the development of complementary food and nutrition information systems on a global basis. Such a framework should be comprehensive enough not only to accomodate "hardware" and "procedural" questions, but also to address institutional, cultural, and political issues. The framework should facilitate the evaluation of trade-offs between timeliness, accuracy, and relevance of information in decision making. Develop new statistical techniques for the collection and analysis of data. Identify the technology or procedures necessary to operate the system (ref. 33, pp 126-127).

The FAO has worked out an international "understanding" on world food scarcity. We recommend that this understanding be institutionalized and that an information system be developed to maintain a permanent information exchange service that:

1. Encourages all cooperating nations to meet the minimum agreed upon storage policies and programs.

2. Provides timely reports on current storage inventories.

3. Maintains liaision with international finance institutions that negotiate loans when and where needed.

4. Maintains up to date files on available transport facilities.

5. Maintains up to date inventories of expected crop yields through remote sensing with five percent deviation from average harvest serving to alert the agency.

6. Encourages research that will result in reduced losses of food in storage and in transport.

7. Encourages coordination of research efforts currently carried out by widely dispersed and non-cooperating agencies.

8. Encourages research on generalized geographic data and on the physical and cultural environment of cooperating nations.

9. Disseminates information to all cooperating nations and to individuals in those nations who participate in the world food storage and distribution system.

7.6 CHAPTER SYNOPSIS

Ordinarily, the initial benefits of aerospace research have been enjoyed only by those nations that have sufficient resources to develop and employ advanced technology. Only secondarily did these innovations reach the lesser developed nations. However, agriculture is a worldwide phenomenon; consequently, technological improvements in remote sensing and ag-air will affect all nations of the world. Presently, sixty-two nations employ over 18,000 aircraft in the treatment of 170 million hectares yearly (ref. 34, p. 176). These figures may be conservative. Recent estimates show aircraft production doubling in the last few years (ref. 35, p. 13). As new technology makes ag-air more effective and economical, further increases in utilization can be expected.

Where new technology has been introduced into society, or an existing technology radically improved, society has had to adjust both to the increased output engendered by the innovation, and, more importantly, to new organizational patterns required to make the innovation effective. While the processes are not fully understood, technology certainly influences the development of a society, and it has been persuasively advocated that technology is a key element inducing social change and development (ref. 36). These changes may be considered beneficial or detrimental to the society. A relatively innocuous invention--the steel axe--for example, when introduced by a well-meaning missionary to an Australian aborigine tribe, led indirectly to the breakdown of the family structure, contributed to the emergence of prostitution and eventually helped to destroy the tribal culture (ref. 37, p. 344). Similarly agricultural innovations also can cause unintended effects. While the improved farming techniques employed in the "Green Revolution" greatly increased crop yields for Asian farmers, it also displaced thousands of rural laborers who ultimately flocked to cities ill prepared to handle them (ref. 38, p. 25). Already India has more landless laborers than the entire population of Great Britian; further unemployment could be catastrophic (ref. 38, p. 6). Another example of unexpected effects is the population explosion which often follows an increase in food production. The net effect may be an actual drop in individual nutrition.

Thus, the creator of technology is faced with a dilemma--while technological innovations are designed to improve the quality of life, they may, in fact, cause great stress on societal systems designed to cope with a pre-existing state of technology. If a method designed to increase food production results in the impoverishment of the intended beneficiaries, then the value of that innovation must be seriously questioned.

It is the central thesis of Chapter 7 that aerospace technology must be viewed with a sociological perspective in addition to the traditional technical-economic criteria used to evaluate an innovation. Admittedly, this is a difficult proposition as not all of the sociological effects of a development can be readily forseen. Who, for example, would have predicted the automobile's profound effect on the American character? At one point it was hailed as an environmental godsend saving New York City from a daily dousing of 60,000 gallons of urine and 2.5 million pounds of manure, byproducts of horse-drawn vehicles (ref. 39, p. 263). Nevertheless, while not all of the effects of an innovation can be forseen, an attempt should be made to understand the consequences of a technological creation. Gerbner notes that such an inquiry has historically been neglected.

> Public decisions have been made with little reliable information about alternatives and consequences. Concerns voiced about long-range cultural impact are often lost in utopian myths, in the rural

din of the cult of technology, or in nostalgia for an idyllic past that never was. We believe that it is premature to celebrate, too late to regret, and too dangerous to ignore what has been set in motion. We must learn how to navigate--andchannel--the cultural currents of our own making, and to steer a course based on reason and evidence toward goals of our own choosing (ref. 40, p. 8).

In an era where societal interdependence insures that cultural disruption will affect all of the world's systems, scientists can no longer afford the luxury of divorcing their work from its consequences. Perhaps there was a time where one could justify German rocket research efforts, as Werner Von Braun was alleged to do, (ref. 40, p. 539) by explaining that "I put the rockets up, where they come down is not my department." But now, neither NASA nor any other research agency can afford to be so myopic. Where the burden of responsibility for the use of an innovation cannot be easily placed upon a single party, then all parties involved must equally share in that responsibility.

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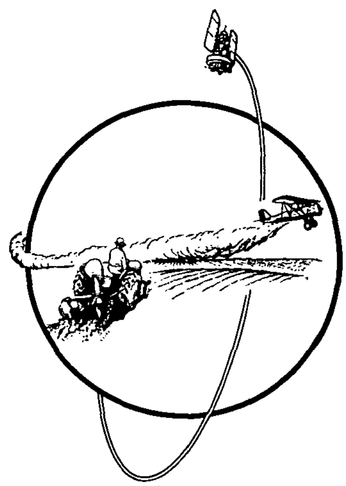


Selected Topics

CHAPTER 8

SELECTED TOPICS

8.1 INTRODUCTION

This chapter does not attempt to focus discussion on one identifiable aspect of agriculture. Instead, a number of topics relating to agriculture have been collected, and each is presented as a seperate section. We feel that these monographs offer insights into the agricultural process, and are of sufficient importance to warrant their inclusion in a separate chapter.

Five sections discussing specific aspects of the agricultural process are presented.

USES OF AIRSHIPS IN AGRICULTURE

In an era of high energy costs, the airship may become a sensible alternative to aircrafts and satellites for many agricultural tasks. This section discusses the performance record of those airships presently in operation, and speculates upon the potential uses of airships in the future.

COMPUTER SIMULATION: OPERATIONAL ANALYSIS OF AERIAL APPLICATIONS

There are two problems associated with the design of new technology for agriculture. First, parameters affecting productivity must be understood. Second, a low cost method to test new designs is needed. A computer simulation model is presented to help solve these problems.

AQUACULTURE/MARICULTURE: AGRICULTURE OF THE SEAS

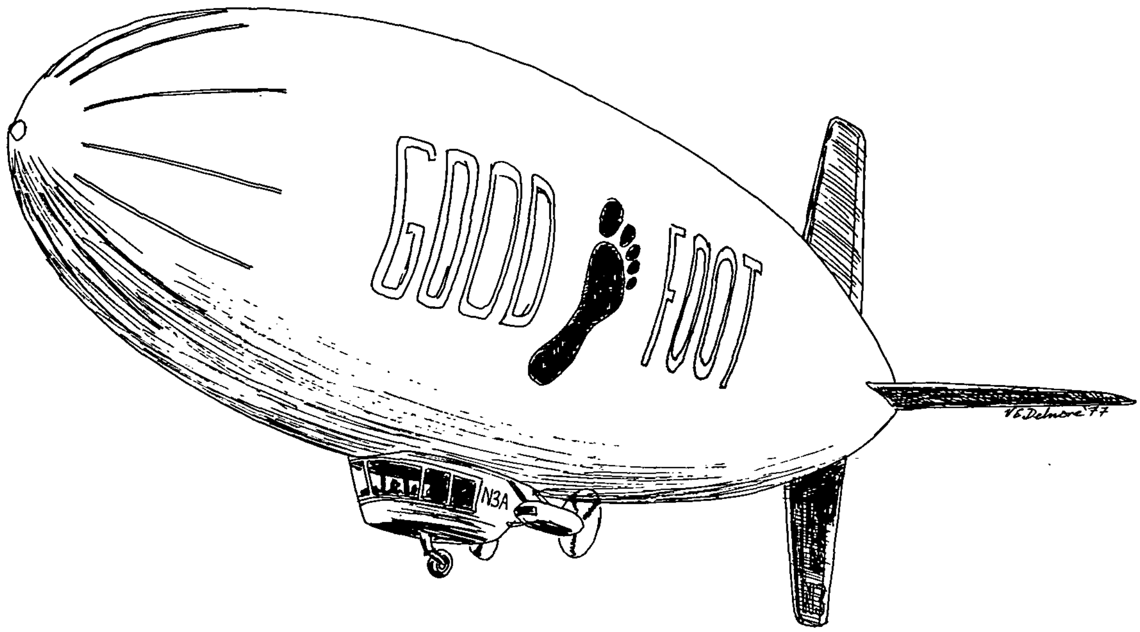
This section investigates methods to improve our utilization of aquatic resources. Aquaculture, growing aquatic organisms in controlled conditions, and mariculture, the exploitation of deep sea resources, are discussed. The section concludes with a list of suggestions for increased NASA participation.

SPACE FARMING: AGRICULTURE IN SPACE

If man is to exist for long periods in outer space, he must be able to generate his own supplies of food and oxygen. This section suggests that agricultural techniques used on the earth may be one solution. Also, the unique environment of outer space may provide an excellent laboratory for experiments designed to improve terrestrail crop species.

LEGAL PROBLEMS ASSOCIATED WITH AEROSPACE TECHNOLOGY AND AGRICULTURE

Four legal problems associated with the introduction of aerospace technology and agriculture are considered in the final section. First, liability problems caused by pesticde drift will be analyzed. Next, the pesticide policy of the Environmental Protection Agency (EPA) is discussed. Finally, two rapidly developing legal areas, weather modification and remote sensing, are investigated.



8.2 USES OF AIRSHIPS IN AGRICULTURE

In choosing types of aircraft for development to meet agricultural needs, the airship must not be overlooked. The airship's low-speed maneuverability, great endurance, large payload, and ability to operate from limited ground facilities makes it very attractive for certain agricultural tasks.

America's fleet of airships presently consists of three blimps built and operated for publicity purposes by the Goodyear Aerospace Corporation, and a few privately-developed experimental dirigibles of various descriptions. The Goodyear crafts are proven designs based on that company's decades of experience in designing, developing, and building dozens of lighter-than-air machines for the U.S. government. In the last fifty years, more than one million passengers have been safely carried on various Goodyear publicity blimps. A major reason for their excellent safety record has been their use of nonflammable helium as the lifting gas rather than the explosive hydrogen of earlier days.

In addition to public-relations duties for their parent company, the Goodyear airships (Mayflower, Columbia, and America) have been used in various scientific projects. According to Goodyear pilot, Ron Bell (ref. 1), they regularly participate in tracking whale migrations off the California coast, and have been used as stable platforms for land surveying, crop inventory and environmental pollution studies.

Surveying, Monitoring, and Inventory

The airship provides a stable platform for sensing instruments, visual observation, and survey operations. The airship has a decided advantage over fixed or rotary-aircraft in this type of work because of its ability to maintain a given position for extended periods of time. It also has an advantage over orbiting spacecraft such as Landsat because, while it cannot cover as wide an area as the spacecraft, it can provide much finer picture resolution at shorter reaction times.

This capability for detailed and prolonged study makes the airship a desirable vehicle from which to perform accurate land surveys, crop inventories and water pollution studies. An airhip even has the capability to momentarily descend in order to collect its own ground truth data. In 1931, the venerable *Graf Zeppelin* completed a 13,300 km scientific expedition to the Artic and the flight included several planned descents to the sea surface to collect data (ref. 2).

If American aquaculture is to develop, then American offshore fishing interests must be protected. The U.S. Coast Guard has a responsibility to monitor and enforce fishing regulations over the recently-declared 200 mile offshore territorial limit. The Coast Guard is hindered in discharging this duty by the lack of a class of vehicles which can adequately patrol large areas of ocean quickly and efficiently, an also directly contact or board vessels. Presently, the Coast Guard tries to do this with fast-moving airplanes which can patrol large spans of ocean, and then summon a cutter to board a ship if necessary. Closer to shore, a helicopter can possibly fulfill both functions. An airship could not only patrol great stretches of water efficiently (witness the U.S. Navy experience of World War II: eight million km^2 of ocean surface protected from hostile submarines by a few dozen airships), but could also deploy, protect, and recover a raft and several persons to board and inspect a fishing vessel. Thus, a fleet of modern airships would greatly improve the Coast Guard's ability to carry out its new duties and responsibilities. These responsibilities must be met if the United States is ever to realize a healthy marine fisheries industry.

Aerial Application

According to Frank Hogan, another blimp pilot and Goodyear's assistant manager of airship operations, airships would not be useful vehicles for crop-dusting or other aerial application tasks in agriculture (ref. 3). This is because the airship is unable to maintain a desired buoyancy while continually releasing materials onto the ground, and the distance it requires to complete a turn.

Transportation of Harvest or Stock

For transportation functions, however, in which a perishable harvest must be moved from a relatively remote area and moved in a limited amount of time, the development and use of airships should be considered (ref. 4). It is probable that some areas of inaccessible but otherwise attractive land would be opened up to agriculture if the transportation problems could be solved.

The German Wullenkemper organization has been using nonrigid airships to carry citrus harvest from interior regions of Africa out to where it can be loaded onto more conventional forms of transportation (ref. 3). This agricultural use of airships has been underway for two years, and has proven to be economically successful.

An airship with a five metric ton payload would be especially useful in logging operations in timber areas where the construction of truck roads is particularly damaging to the environment. The airship would not need the roads upon which the truck depends, and would not produce the undesirable noise and downwash characteristic of heavy-lift helicopters.

Many high-value crops, such as grapes, are harvested on terraced hills and must be removed quickly. Here also, the airship would be in competition with the truck, and again the ability to handle bulky loads without requiring roads may make it attractive.

The transfer of livestock is presently accomplished by rail, truck or herding. The first two are objectionable because of stress to the animals while in transit. The third requires expensive labor and is time-consuming. There have been occasional uses of cargo airplanes for transoceanic transfer of cattle. An airship with a 25 to 100 ton payload could easily move live animals up to 300 km in a low-noise, low-acceleration environment.

To take on a heavy load in a remote area, an airship would probably not need to actually land. Instead it would momentarily stop, haul up the cargo in prepacked containers, drop ballast in order to maintain a desired buoyancy, and leave. If it were necessary to actually land, no conventional airstrip would be needed, and the airship could be held down by line handlers while the cargo is loaded. Mooring to a portable mast is possible, but would be necessary only if the airship were to be on the ground for extended periods. Ideally, the airship would be slightly heavy (a few hundred pounds or so) at takeoff, and make a short run in order to develop dynamic lift. A positively buoyant vertical lift off, however, could be used in areas where a takeoff runs could not be made. This would require that there be a slight decrease in payload. Both types of landing and both types of takeoffs were used extensively by the U.S. Navy in its wartime operations with airships. These operations included all sorts of maneuvers in jungles, deserts, and mountains, and were made in all types of weather (ref. 5, pp 80-85).

Reliability and Operation

The current generation of airships includes the three Goodyear blimps in the United States and forth one (Europa) based in Italy, the Wullenkemper ships, some in use in Japan and a fleet of twenty-two presently under construction in England for use in Venezuala. Past experience suggets that modern airships have good serviceability in the field. The engines are all of standard design and require no special parts. In fact, the engines to be used in the Venezuelan ships are standard Porsche automobile engines. The navigation systems and avionics are standard for general aviation. There are no mechanical parts (such as a helicopter's rotor hub) that call for specialized mechanics or which must be kept within very narrow specifications. The only components which are truly unique are the outer skin, or envelope, and the internal curtain by which the gondola, or control car, is suspended. However, new outer cover materials using dacron covered with polyurethane will give the Venezuelan ship envelopes a useful life of ten years (ref. 6). The skills necessary to maintain such materials in the field, under varying conditions, are currently found among sail makers, parachute riggers, persons who operate hot-air balloons, and of course, among the ground crews of presently-operating airships. The Goodyear crews have been eminently successful at maintaining their airships over thousands of miles of operation away from home each year.

The U.S. Navy airship experience of World War II illustrates the reliability of airships. Some 160 nonrigid airships were based around the world and flew a total of 550,000 flight hours to patrol nearly 8 X 10^6 km^2 of ocean. Of the airships assigned to the fleet, 87 percent were "on line" (either in actual operation or in readiness for operation) at all times. This figure is very high for wartime activities of aircraft (ref. 5, pp 80 & 116).

The airships mentioned so far are non-rigid; that is, there is no internal structure. If future airship designs employ either internal structures, compartmentalized cells, or rigid hulls, then the complexity of construction and maintainance will increase.

Pilot certification for airship operation is quite demanding. In the United States, the FAA requires 200 hours of in-type flight for a license. The Goodyear Aerospace Corporation requires of its pilots an additional fifty hours, plus a fixed-wing instrument rating. Goodyear normally maintains about twenty airship pilots in flight status, and operates an extensive ongoing training program.

Safety

Modern airships are multi-engine aircraft, which decreases the probability of losing all power. However, as long as an airship maintains some buoyancy, it is capable of a safe landing on an unprepared field, even with total loss of power.

A nonrigid airship (for example, a Goodyear blimp) has a flexible hull maintained by internal pressure. Because of its flexibility, fabric stresses are minimized, and any moderately-strong deflection is quickly relieved (ref. 5).

Rigid hull designs, while not offering the safety of a flexible hull, do utilize compartmentalization of the gas cells. The effect of a leak therefore is usually confined to only one cell, and only a fraction of the total static lift is lost.

Also, the use of helium rather than hydrogen as a lifting gas eliminates the possibility of a fire or explosion, except in the cargo or in the engines. Emergencies originating in cargo or in the engines of course are possibilites for any type of vehicle.

TABLE 8-1

Table 1 - Input Data

INPUT DATA

Mission Variables

Variables	
Coordinates of Base	miles
Number of Loading Points	
Coordinates of Loading Point	miles
Number of Fields per Loading Point	
Air Density	slugs/cu.ft.
Taxi Distance at Loading Point	feet
Coordinates of Fields	miles
Rate of Application on Field	lb./acre
Field Area	acres
Length of Field	feet

Airplane Variables

Number of Aircraft being Evaluated	
Aircraft Name	
Aircraft Identifier Number	
Maximum Ejection Rate	lb./sec.
Wing Area	sq. ft.
Empty Weight	pounds
Payload	pounds
C_L in Turns	
Taxi Speed	M.P.H.
Swath Speed	M.P.H.
Takeoff Speed	M.P.H.
Ferry Cruise Speed	M.P.H.
Take Off Distance	feet
Airplane Operating Cost	dollars/hr.
Wing Span	feet

Economic Variables

Time to start (in morning)	min.
Time to prepare equipment to move	min.
Time to survey fields to be treated	min.
Taxi distance at base	feet
Speed at which ground equipment is moved	M.P.H.
Time to prepare equipment to return to base from last loading point	min.
Idle time	min.
Charge for area covered	dollars/acre
Charge for materials applied	dollars/lb.
Rate of loading airplane	lb/sec,
Rent for facilities	dollars/mo.
Insurance premiums, total	dollars/mo.
Office supplies cost	dollars/mo.
Interest paid	dollars/mo.
Freight, parcel post, other shipping	dollars/mo.
Telephone, telegraph, radio charges	dollars/mo
Clerical salaries	dollars/mo
Supervisor & Foreman wages	dollars/mo
Legal, accounting, consultant, other fees	dollars/mo
Number of flagmen	
Rate of pay for flagmen	dollars/hr
Number of truck drives used	
Driver's pay rate	dollars/hr
Pilot's percentage of income (optional)	
Pilot's pay rate, if on flight time (optional)	dollars/hr
Pilot's pay rate, if on elapsed time (optional)	dollars/hr

The potential of mid-air collisions of agricultural airships with other types of aircraft would probably be minimal. Agricultural airships would presumably be operating only in remote regions; thus, they would normally be clear of established airways.

Recommendations

NASA should recognize the appropriateness of lighter-than-air vehicles in certain agricultural functions. Support of research which will improve the reliability, payload, and low-speed maneuverability of airships would do much to improve agricultural surveying, crop inventory, environmental monitoring, and the transportation of produce, timber, and stock. NASA research should be directed toward the application of thrust-vectoring propulsion systems to airships. This would greatly enhance the safe handling capabilities of airships, especially when close to the ground and onloading and offloading freight. Further advances in navigation systems and in avionics will be useful for all types of aircraft, including lighter-than-air.

NASA's research in boundary-layer theory should continue toward improvement of airships and lifting bodies, in order to increase their fuel efficiency when heavily laden with useful payloads. Designs and materials for outer coverings and for internal suspension systems (nonrigid airships) and for internal frames (rigid) should continue to be subjects for research by NASA.

8.3 COMPUTER SIMULATION: OPERATIONAL ANALYSIS OF AERIAL APPLICATIONS

There are two major problems in investigating ways to improve the aerial application of agriculture material. The first is the need to determine how aircraft design parameters, methods of operation, and business and economic factors affect the productivity of an aerial application system. Second, there is the need for the economical testing of new designs and operational practices before committing large sums of development money. To assist in research on these problems, a computer model simulating the flight of an ag-plane has been developed and used (See ref. 7 for explanation of the model).

In order to construct a computer model of an aerial application it is necessary to examine the aerial applicator's "mission". The mission consists of loading aircraft tanks or hoppers with liquid or dry material, flying to a field, discharging material over the field while flying back and forth until the hopper is empty. He then flies back to a loading point, lands, reloads, and repeats these operations until the entire field has been treated. Another field or loading point is then selected and this sequence is repeated. This simplistic view of aerial application must be examined in more detail if it is desired to determine how aircraft design parameters, method of operation, geogrphy, and economic factors will affect the aerial application's productivity.

Productivity may be defined in two ways. On the one hand it may be defined as the technical quality of the application pattern. Quality in this sense refers to the uniformity of material distribution (e.g.,fertilizers), effectiveness of insect kill, and pattern of foliage coverage (e.g., fungicides). On the other hand productivity may be defined in terms of the amount of profit earned by an aerial applicator. The aerial application industry is almost

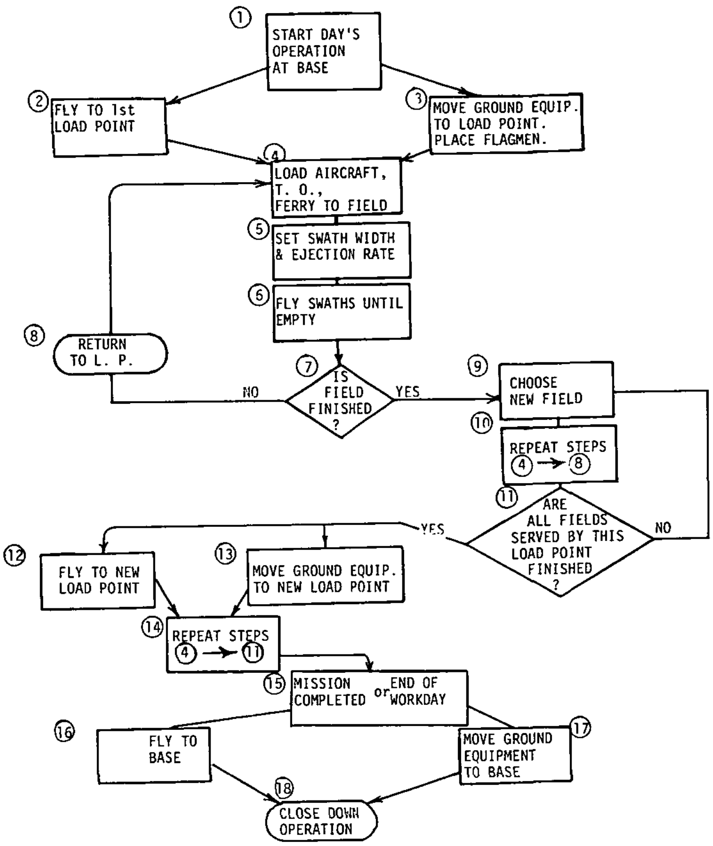


FIGURE 8-2 FLOW CHART FOR OPERATIONS ANALYSIS

exclusively private enterprise, and making a profit is a requisite for staying in business.

In writing the program two requirements were imposed. First, the primary indicator of the merit of a particular aircraft or operational practice would be profit. Second, the program would model actual operations as accurately as possible using economic factors, geography of mission, and aircraft design and performance parameters as the problem variables (Table 8-1).

The problem was defined in the following way. The geometry of the fields to be treated (size, shape and location by coordinates) and the rate of application to each field was stated. Locations of base and reloading landing strips were also defined. The operating base was the origin of the coordinate system used. Operational economic parameters were variable inputs.

Each aircraft successively "flies" the same mission shown in outline in Figure 8-2. The performance parameters of each airplane are read into the computer by data cards. The mission begins with preparation at the home base. Ground equipment and personnel are hauled by truck to the loading point for the first set of fields. The plane taxies, takes off from home base, flies to the loading point, makes a brief survey of the job, lands and taxies. The hopper the plane, and moving the ground equipment. Flight time and time spent in turns are accumulated separately. If other fields are to be serviced from another loading point, the operation is moved to that loading point. This move includes transporting ground equipment and personnel as well as ferrying the airplane. At the end of a mission or at the end of the flight day, all equipment is returned to base and the operation is closed down.

Computer read-out consists of five pages. The read-out includes (a) description of mission in terms of location and geography of fields to be treated, (b) specifications of aircraft analyzed, (c) operator's economic factors, (d) performance of each of the airplanes being analyzed on the specified mission, and (e) an analysis of cash flow with the last column being net profit on mission.

The results of studies conducted using this model to compare the productivities of actual ag-planes and a number of "paper airplanes" on various missions are in reference 7. During the present study the computer program has been modified to be compatible with the NASA Langley computer system. Fifty-five different airplane designs were examined with each airplane spraying seven fields from two loading points (Table 8-2).

An attempt was made to specify realistic design numbers for the designs examined. The numbers used were based on aircraft now flying or in advanced preliminary designing.

The ranges of design factors examined include:

Payload	454 to 1818 kg (1000 to 4000 pounds)
Empty weight	864 to 3636 kg (1900 to 8000 pounds)
Ferry speed	38 to 65 m/sec (85 to 145 mph)
Swath speed	38 to 65 m/sec (85 to 145 mph)
Coefficient of lift in turns	1.0 to 2.0
Operating cost	37 to 135 Dollars/hour

Some of the results of this study are shown in figures 8-3 through 8-7. Firgure 8-3 indicates that increasing the lift coefficient (C_L) in the turns increases both productivity (acres service per hour) and profit for the mission. It was assumed in this analysis that the aircraft empty weight remained constant at 1,770 kg (3900 lb) and the payload was 1,134 kg (2500 lb.). It may be found that aircraft weight would have to be increased to attain greater values of C_L (due to complex flaps, etc.). The weight increase would cause a reduction in the increases of profit and productivity, and may reach a point where there would be no increase.

Figure 8-4 shows the effect of aircraft speed on profit. Increasing the ferry speed from the airfield to the field increases profit. Increasing the speed at which the swath is flown is not desirable except at quite low speeds.

TABLE 8-2

AERIAL APPLICATION OPERATIONS ANALYSIS

DESCRIPTION OF THE MISSION TO BE ACCOMPLISHED

THE MISSION CONSISTS OF MOVING AIRCRAFT AND GROUND EQUIPMENT FROM A BASE TO A SERIES OF LOADING POINTS. FROM EACH LANDING POINT A GROUP OF FIELDS IS SERVICED. THE LOCATIONS OF THE FIELDS ARE LISTED BELOW, WITH THE AREA AND RATE AT WHICH MATERIAL IS APPLIED TO EACH. THE SECOND TABLE LISTS THE SPECIFICATIONS OF THE VARIOUS AIRCRAFT CONSIDERED. THE PERFORMANCE OF EACH OF THESE AIRCRAFT IN PERFORMING THE MISSION AND THE RESULTING COSTS AND EARNINGS ARE ALSO TABULATED BELOW.

LOCATION	FIELD COORDINATES X (MILES)	FIELD COORDINATES Y (MILES)	FIELD AREA (ACRES)	RATE OF MATERIAL APPLICATION (POUNDS/ACRE)	SWATH LENGTH (FEET)
BASE	0.00	0.00			
LOADING POINT NO. 1	5.40	3.80			
FIELD NO. 1	2.20	4.00	90.0	200.0	1300.
FIELD NO. 2	5.40	4.00	120.0	120.0	2600.
FIELD NO. 3	7.90	4.00	90.0	90.0	1500.
FIELD NO. 4	8.40	2.80	160.0	150.0	2600.
LOADING POINT NO. 2	12.50	3.80			
FIELD NO. 1	9.00	4.00	90.0	200.0	1300.
FIELD NO. 2	11.50	6.00	160.0	250.0	2600.
FIELD NO. 3	12.50	6.00	160.0	200.0	2600.

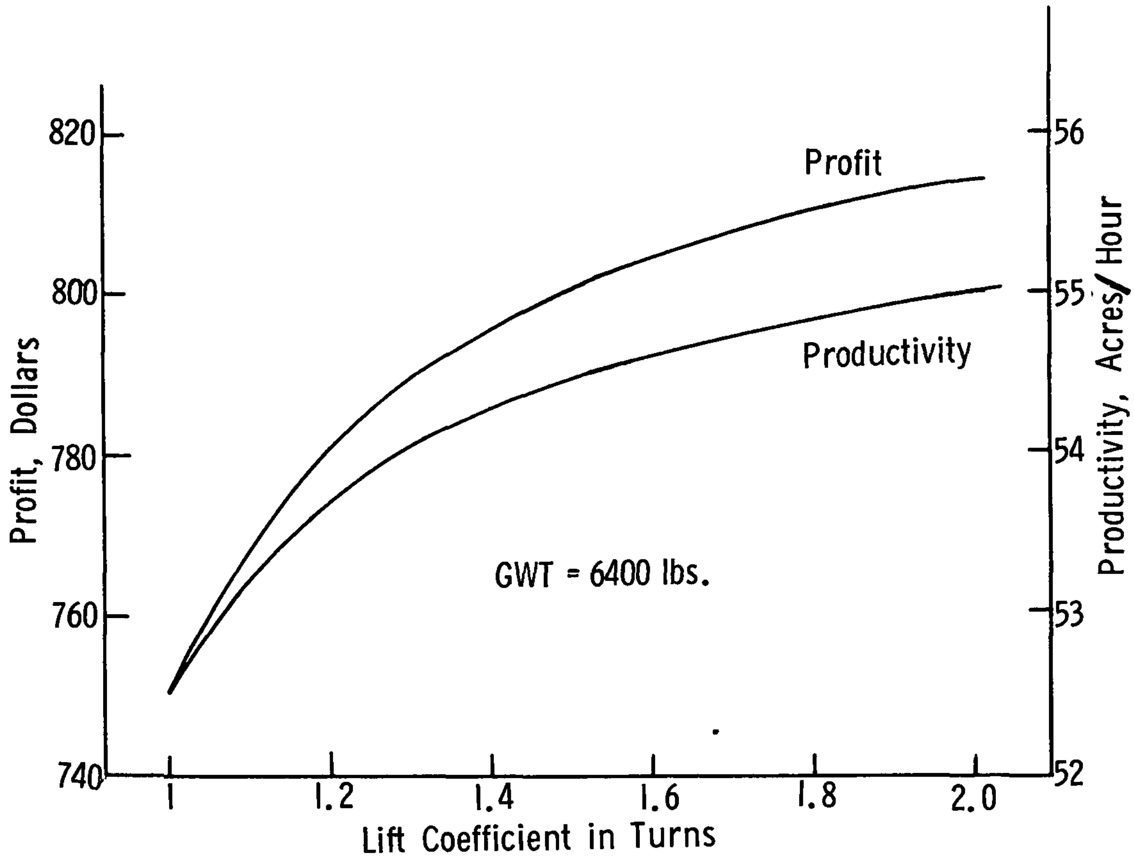


FIGURE 8-3. EFFECTS OF LIFT COEFFICIENT ON PRODUCTIVITY FOR SHORT FIELD-CROP MISSION

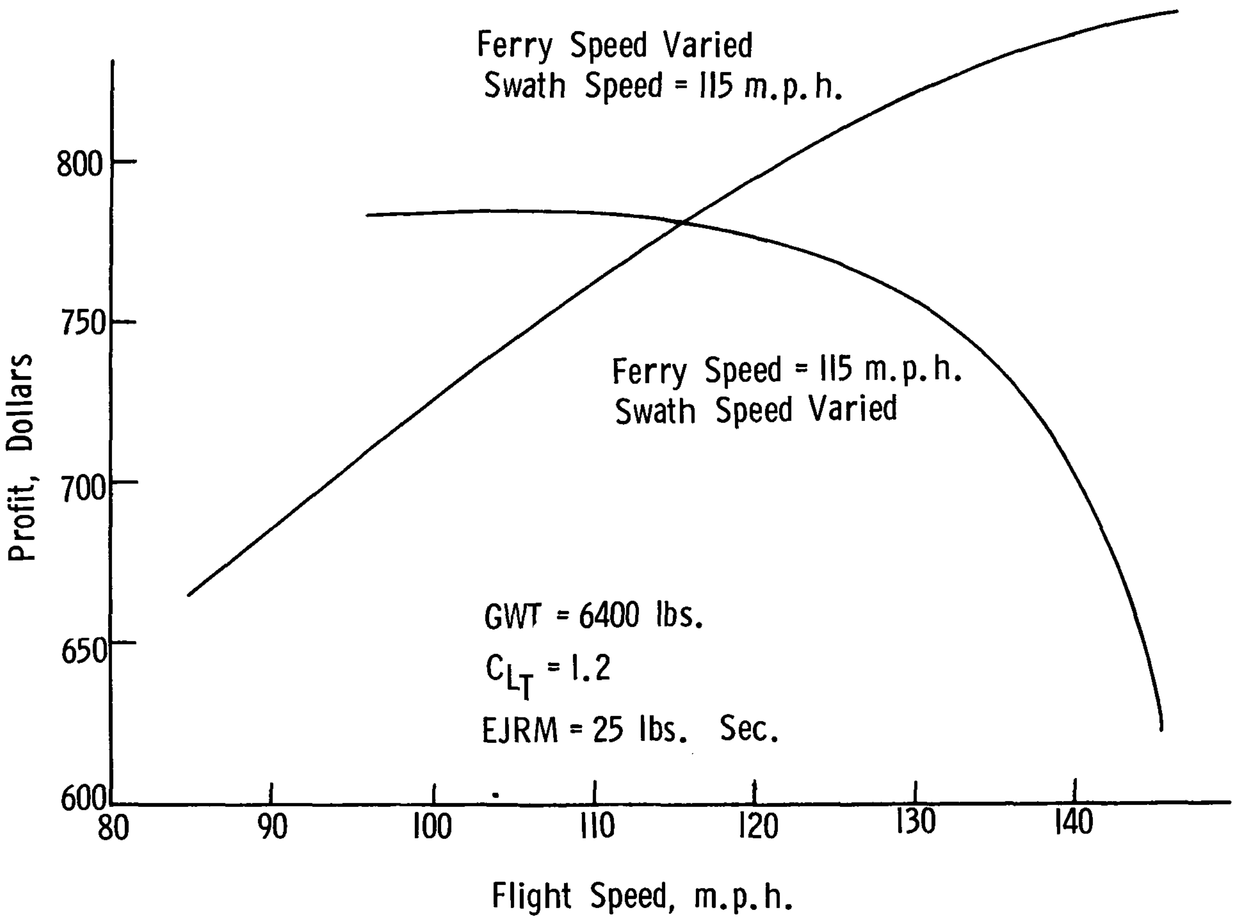


FIGURE 8-4. EFFECTS OF CHANGING AIRCRAFT SWATH SPEED OR FERRY SPEED, SHORT FIELD-CROP MISSION

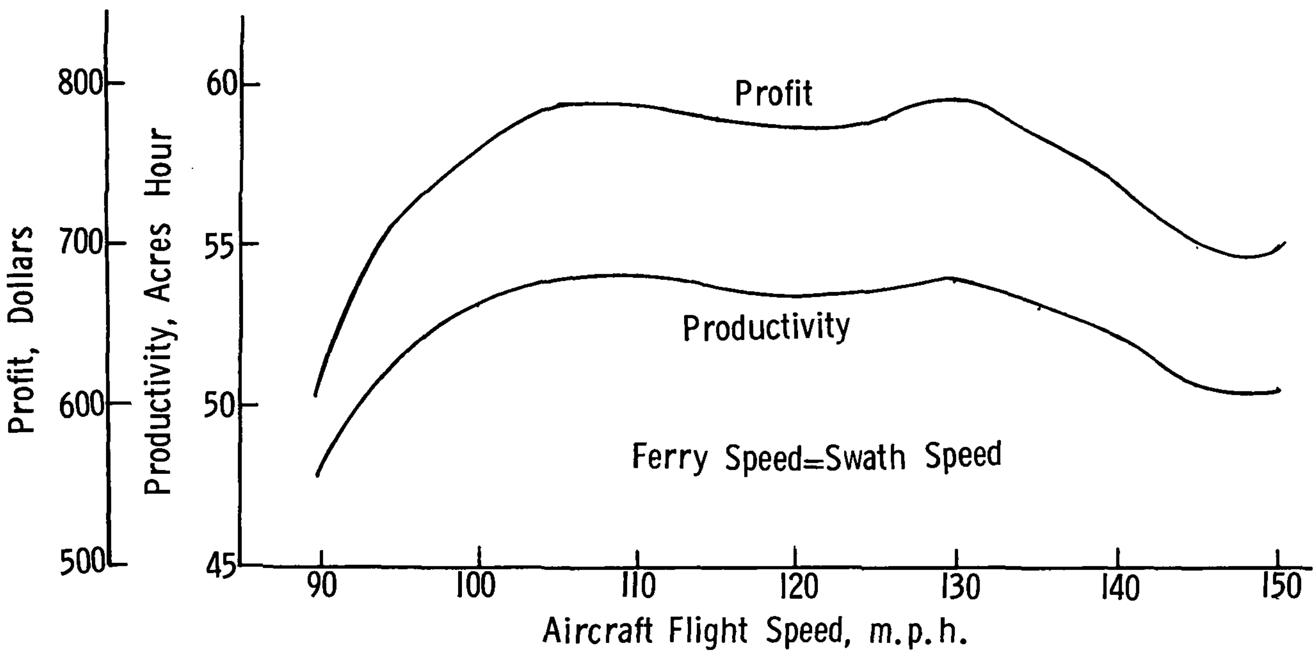


FIGURE 8-5 EFFECTS OF CHANGING BOTH FERRY SPEED AND SWATH SPEED.

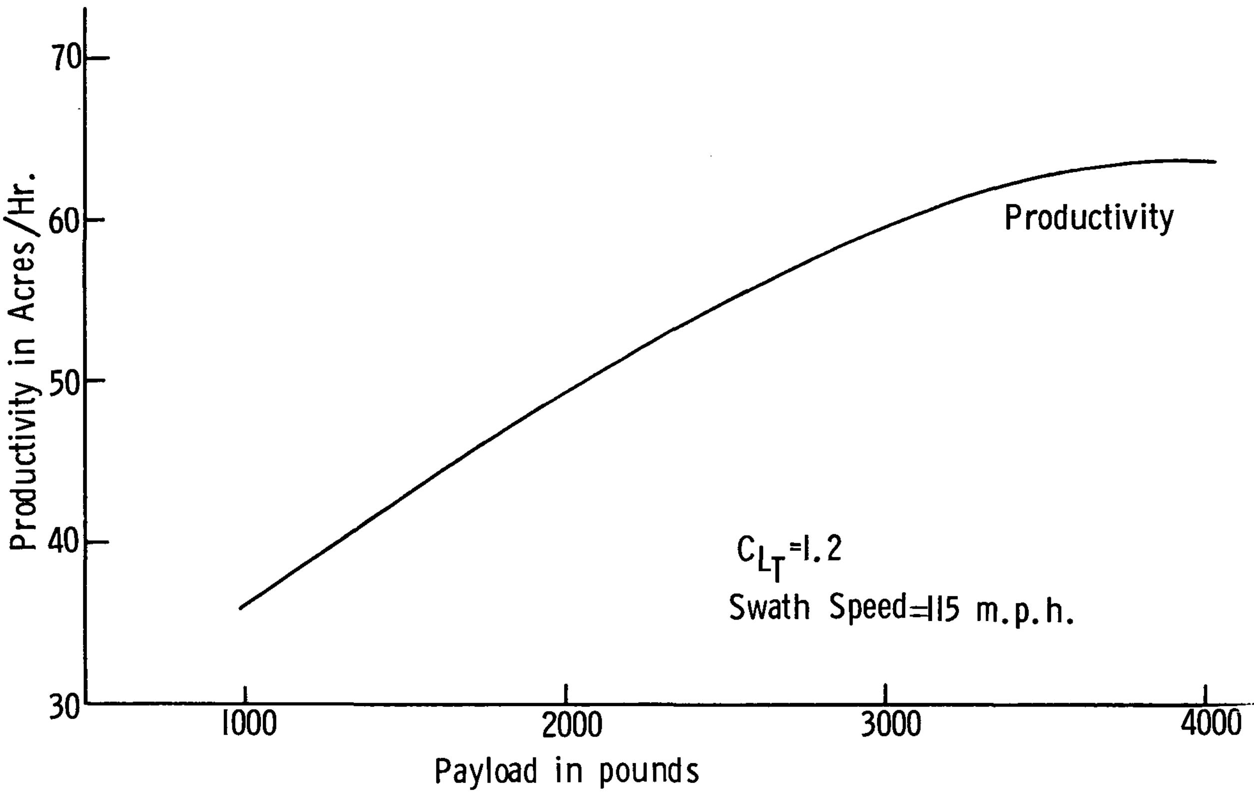


FIGURE. 8-6 EFFECT OF PAYLOAD ON PRODUCTIVITY FOR SHORT FIELD-CROP MISSION

is loaded, the plane taxies, takes off, and flies to the first field. Swath width is computed for each airplane as a function of the rate of application, swath speed, wing span, and any known limitations of the airplane. It appears that the limiting factor on swath width is the maximum ejection rate, measured in pounds per second, and the rate is dependent upon the type of dispensing equipment. Up to fifteen aircraft may be analyzed in a given problem.

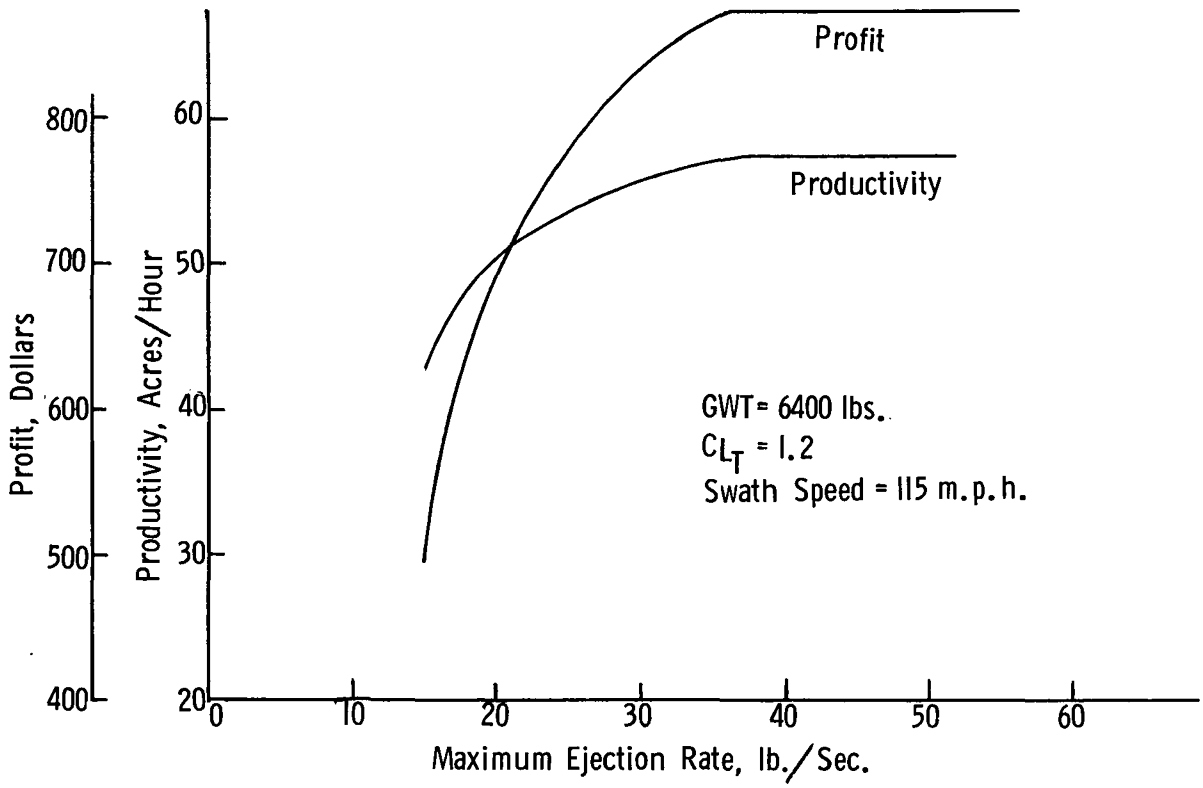


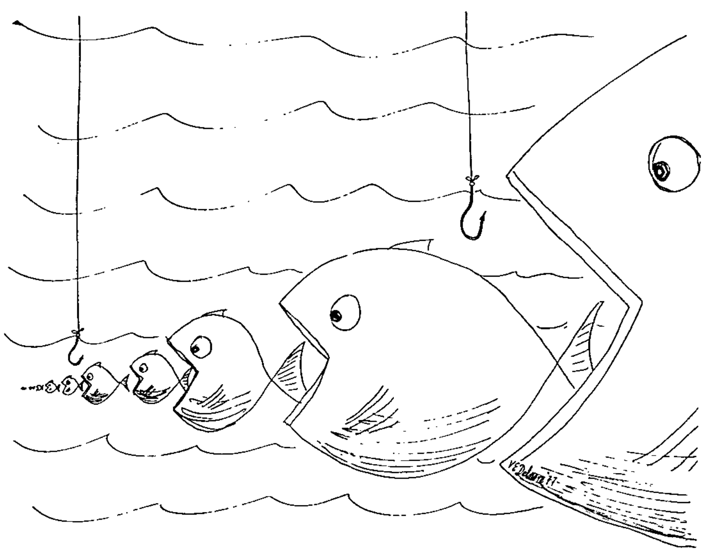
FIGURE. 8-7 PRODUCTIVITY AND PROFITABILITY AS AFFECTED BY AIRCRAFT MAXIMUM EJECTION RATE

In the program, the pilot flies a swath, makes a turn and flies the next swath. Before each swath, a check is made to assure that sufficient material remains in the hopper for another swath. If not, the plane is flown back to the loading point with the material in the hopper tabulated as "dead headed". The plane lands, taxies, loaded, taxies, takes off, and returns to the field where material is again applied. This procedure continues until all the fields to be serviced from that loading point are completed. During this operation, the computer accumulates total elasped time caused by ground servicing, flying

The interaction between rate of ejection, amount of material to be applied to each acre, and swath speed serves as a definite limit on the speed the swaths can be flown. Changing both swath speed and ferry speed has complex effects, as shown in Figure 8-5.

Figure 8-6 indicates that increasing aircraft size increases productivity. This does not mean the most productive is not necessarily the most profitable aircraft. The aricraft's operating costs determines profit. Figure 8-7 confirms results reported in reference 7. Increasing the maximum ejection rate dramatically increases productivity up to a maximum. The relationship between payload, swath speed, and ejection rate limits the effectiveness of this method of improving productivity.

A complete study of various design parameters, of operating conditions, and of types of missions needs to be made using this model. In addition it is recommended that NASA and/or airframe manufactures use the model to evaluate new ag-plane designs.



8.4 AQUACULTURE/MARICULTURE: AGRICULTURE OF THE SEAS

Mankind has not yet fully utilized the potential of the earth's aquatic resources. Exploitation of these food resources falls under two broad catagories--aquaculture and mariculture. The former is "...the growing of aquatic organisms under controlled conditions" (ref. 8, p. 2). Mariculture, as used here, refers to the exploitation of deep-sea resources. The discussion that follows touches briefly upon the current status of aquaculture and mariculture, some proposed public policies for expansion of these activities, and the current and potential contribution of aerospace technology to mariculture.

Aquaculture: Current world production of fish is approximately 71 million metric tons. Of this figure some six million metric tons are produced under controlled conditions--aquaculture. Sixty-six percent of aquaculture production are fin fish, 16.2 percent are mollusks, 17.5 percent is seaweed while .03 percent are crustaceans (ref. 9, p. 5). Most of this production occurs outside the United States, primarily in the Indo-Pacific regions.

The United States is not self-sufficient in fish production; fully 50 percent of U.S. fish consumption, by weight, are imported. The annual cost of these imports is approximately 1.5 billion dollars (ref. 10, p. 295). Significant increases in U.S. fish production, through either aquaculture or mariculture could potentially reduce U.S. balance of payment deficits.

Aquaculture is cost-effective protein source. Cost benefit ratios of feed input to production outputs of shrimp are projected to be about 2.8 to 1. This compares favorably with commercial production of chickens at 3.8 to 1 or the much higher conversion ratios for cattle and swine (ref. 10, p. 135).

In an effort to stimulate aquaculture production, the federal government has begun funding aquaculture programs. In fiscal year 1975 this funding amounted to some $15,721,000 (ref. 10, p. 293). Approximately one fifth of these funds went to universities under a program known as Sea Grants. Sea Grants are designed to engage research resources of universities problems of marine science. The remaining funds were dispersed by a number of agencies including the agricultural extension services of the USDA, the Fish and Wildlife Service and the Cooperative State Research Service.

In May 1977 the National Oceanic and Atmospheric Administration (NOAA) published the "NOAA Aquaculture Plan". The report indicates that aquaculture in the United States consists largely of the following crops: salmon, trout, catfish, oysters and shrimp. The report went on to suggest that there are six priority crops that should be focused upon to achieve optimal advances in aquaculture--salmon, marine shrimp, fresh water prawns, lobsters, oysters and marine plants.

There are a number of obstacles to increased production of these species which can be resolved through government-sponsored research and development. For example, world-wide demand for marine shrimp is high, and demand is expected to increase 25% by 1985. Although the life-cycle of the species is understood marine shrimp have not been successfully bred in captivity. Disease control and effective water purification techniques are also obstacles to an increased harvest of this species. Accordingly, NOAA has proposed annual expenditures of $1,200,000 beginning in fiscal 1979, for development of shrimp resources (ref. 11, p. 13-16).

The NOAA overall aquaculture plan calls for annual expenditures of $19 million by 1979 and continuation at that level through 1989 (ref. 11, p. vi). This would constitute a major increase from the current funding of $6.4 million in 1976.

Development of commercial aquaculture, is obstructed by competition for coastal space allocations. Competition along coast lines and in marine estuaries comes from housing, recreational and industrial interests - - none of whom are prepared to concede priority to aquaculture. Problems of this nature make mariculture (exploitation of deep-water marine resources) more attractive.

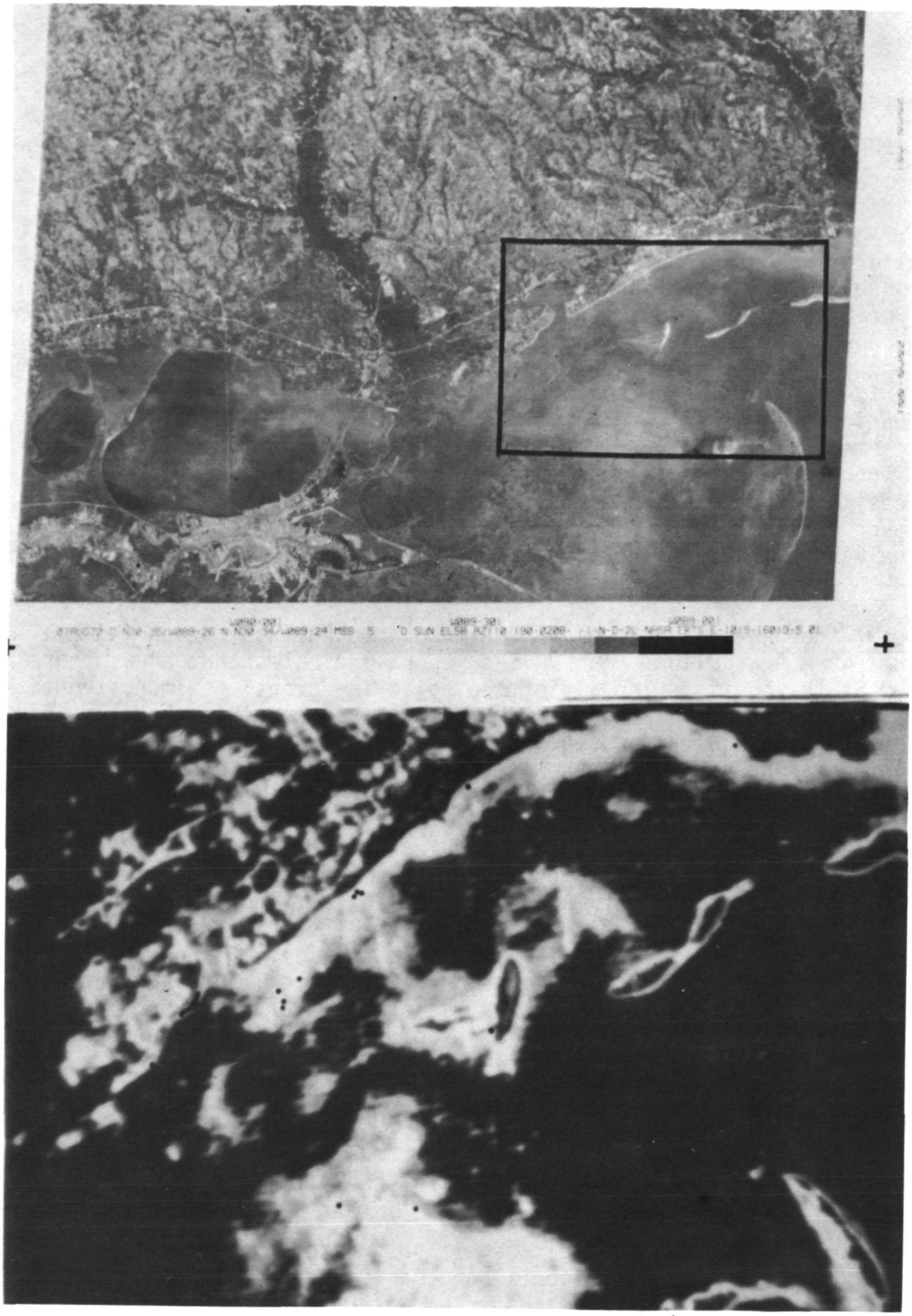


FIGURE 8-8 LANDSAT IMAGERY OF MENHADEN FISH SCHOOLS NEAR BAY ST.LOUIS,MISS.

Mariculture: One of the ways in which the sea's potential for supplying food may be more fully realized is for man to tap into the marine food chain at a lower trophic level. For example, to produce a given weight of Japanese yellowtail tuna; other fish weighing eight times the given weight must be eaten by the yellowtail. It would be far more efficient and less costly for humans to harvest and consume the fish eaten by the tuna. As long as the practices of major fishing industries remain inefficient, fish protein will remain a luxury item rather than a staple food (ref. 12, pp 427-430).

Commercial Catch: The world commercial catch is currently 65 million metric tons per year. The potential for exploiting this resource is estimated at many times this amount; however, the maximum potential using conventional methods is probably no more than 2 to 4 times current production (ref. 12, pp 195-196).

To accomplish a manifold increase, new species, such as the Antarctic krill (Euphausia superba) must be harvested. Krill are particularly attractive due to their low trophic level. Krill exist in such abundance that potential yields from this source have been placed, conservatively, at 100 million tons per annum. To maximize this resource, however, increased knowledge of the lifecycle and migration patterns of these creatures is necessary (ref. 13, p.196).

There are two problems which inhibit effective harvesting of krill. The first is that of acceptance, i.e., getting people (particularly North Americans) to accept krill as a dietary staple. The second problem is the economics of harvesting an Antarctic crop and transporting it to the market place. While technically feasible, the cost benefit ratio of a krill harvest is still unacceptable; however, as the cost of production of conventional food sources continues to increase, alternatives such as krill become more attractive.

An alternative method of exploiting krill would be to utilize them as food for stocks of predator fishes. Once the life-cycle of the krill is fully understood, it might be feasible to release certain predator species and then harvest the predator. Some species of salmon might be particularly suited to such an endeavor.

Salmon return to familar waters to spawn. Scientists now know that it is the scent of the home waters that the salmon seek (ref. 14, p. 42). It might be feasible to release hatchery-reared salmon from land bases at the extreme tip of South America, or to release them from hatchery ships in the immediate area of the krill. At maturity, the harvest vessels could return to the area, release the prescribed scent, and harvest the catch. In the case of land bases the salmon would return to the hatchery.

Use of Offshore Platforms: The possiblity of utilizing offshore platforms for aquaculture is made attractive by the two hundred mile limit and increased demand for offshore petroleum products. Experiments into multiple uses of oil platforms are now underway in the Gulf of Mexico (ref. 15, p. 363). Two food sources which could be exploited through the use of these platforms are mollusks and shrimp. Natural open-sea platforms also exist. The lagoons of atolls provide natural boundaries for aquaculturing of a variety of marine species.

Environmental Manipulation: Stimulating the Growth of Phytoplankton

There are two ways to stimulate the growth of phytoplanktons--artificial upwelling and the application of terrestrial fertilizers. Artificial upwelling consists of the pumping of deep-water nutrients up to shallower depths where the phytoplankton grow. Experiments in the Virgin Islands, where nutrients were pumped into tanks, indicate that such a process is feasible (ref. 15, p. 170). Where natural upwelling occurred, higher fish yields were obtained because the increased nutrients in the water could support higher volumes of life.

Given a two hundred mile limit, exploiting the seas as pasture becomes possible. Artificial upwelling would provide the fertilizer. The pasture could then be stocked from hatcheries or though increases of natural stocks. A number of technical problems must be resolved before such environmental manipulation would be feasible. Artificial upwelling is technically possible using platforms; however, holding the nutrient-rich water near the surface long enough to have an effect is as yet unresolved on a large-scale basis.

If upwelled water is to be used, two solutions have been suggested. The first is to dilute the water with freshwater, the second is to heat it. Both methods would be expensive (ref. 15, p. 171). Experimentation to determine the cost-effective way of providing the needed retention is in order.

The environmental impact of artificial upwelling is as yet unknown. Before proceeding to implementation, investigations to determine the potential impact must be conducted.

An alternate method of stimulating primary growth of plankton is to distribute terrestrially-produced fertilizers in the seas. Solid fertilizers are unsuited for aquatic application due to their having a higher specific gravity than water. Liquid fertilizers might work, but some reformulation would be necessary (ref. 15, p. 165). A second possibilty would be to convert human waste to fertilzer, although a number of technical problems, such as detoxification of the waste, remain to be solved (ref. 15, p. 164).

Since mariculture is in the experimental phase and because of the potential for environmental damage in biomodifications such as those touched upon here, all possibilities should be explored. Not enough is known about marine environment in general or about life cycles of particular species to allow for free exploitation. In seeking to understand the environment of the seas, there is a definite role for aerospace technology.

NASA is currently working on a number of projects that are directly involved in expanding our understanding of the marine environment. The remainder of this section reviews these projects and makes some recommendations for further applications.

NASA Activities: NASA is currently experimenting with the applications of remote sensing technology as a tool to increase man's understanding of the marine environment. These activities include water quality studies at Langley

Research Center and at Goddard Space Flight Center. In addition, NASA is engaged in contract work in remote sensing of living marine resources. This latter activity is carried out at the National Oceanographic and Atmospheric Administration's test facility at Bay St. Louis, Mississippi.

The Langley activities involve quantitative mapping of chlorophyll in the coastal zone, studies of phytoplankton (using remote sensing), mapping eel grass habitats for clams, and conducting spectral signature investigations of water quality relative to coloration (ref. 16). The chlorophyll and phytoplankton research utilizes a ten-channel modular multispectral scanner which is flown in an aircraft platform at an altitude of 2,400 m (8,000 ft.).

Chlorophyll levels are a significant parameter in water nutrient loads and pollution. Extremely high or low concentrations of chlorophyll indicate presence of pollutants. High levels of chlorophyll indicate high nutrient levels and are indices of sewage and industral pollution. At the other extreme, low chlorophyll levels are an index of chemical toxicity (ref. 17). The capacity to monitor environmental parameters, such as is attempted in the Langley research are potentially important factors in the exploitation of marine resources.

Research at NOAA's Bay St. Louis facility is proceeding in two important phases. Remote sensing is being used in the detection and enumeration of giant bluefin tuna (ref. 18), and in investigations of the movements of schools of menhaden. ERTS-I (LANDSAT) data was correlated with data gathered from aircraft and with sea truth data (ref. 19, p. 11). The study did not monitor the menhaden per se; rather, the association of back-scattered light, chlorophyll concentrations, and water transparancy were used as an index of the presence of menhaden. The study was highly successful - - menhaden were generally found with these water conditions. The potential of remote sensing in the harvest of commercial species is immediately apparent. This technology, moreover, could be useful in improving our understanding of the life cycles of species such as tuna and krill.

Research at the Goddard Space Flight Center has investigated chlorophyll content using imagery from a ten-channel ocean scanner (.433um to .722um) mounted in a NASA U-2 aircraft which was flown at 19.8 km (65,000 ft.). A secondary purpose was to test the instrumentation for future use on Nimbus G, a meteorlogical satellite scheduled for launch in 1978.

Other immediate benefits have resulted from the signature work. These benefits include information about waste dump and sediment plumes in the Hudson Bight, sedimentation in former clam beds (now condemned) in the Chesapeake Bay, and the red tides in Florida (ref. 20).

Skylab has also been used to investigate the upwelling of ocean waters off the coast of Africa. This study demonstrated that correlating ocean color change with temperature gradient data from Skylab imagery was an effective method for estimating biological productivity in the upwelling region (ref. 21).

<u>Recommendations</u>: The open oceans and the marginal seas are potentially bountiful. Before these resources can be fully exploited however, a great deal of research is in order. The following is a list of potential endeavors:

1. Fish Biology: Large scale funding for research into the life cycle of a number of species would yield necessary information regarding feeding habits, migration and, most importantly, reproducitve processes.

2. Harvest Technology: Successful exploitation of potential species will require experimentation with new harvest technologies; moreover, the United States cannot fully exploit the 200 mile limit without the introduction of large scale systematic processing efforts on the part of the commercial fleet.

3. Remote Sensing: Funding should continue for programs which would further enhance - (a) the quality of the imagery and its uses in water quality assessment and (b) life cycle of fishes as well as the monitoring of fish movement, (c) finally, systems for the utilization of remote sensing data must be divised.

4. Ecological Modifications: More information is needed regarding the environmental impact of (a) artificial upwelling and (b) terrestrial fertilizing of the seas must precede the widespread employment of these techniques. (c) Improved methods of detoxifying sewage and industrial waste must be explored if the dumping of these materials into the aquatic environment is to continue.

8.5 SPACE FARMING: AGRICULTURE IN SPACE

Two examples of possible agricultural activity in space are discussed below One in spite of, and the other to take advantage of, the enviromental characteristics of space.

Because of the inhospitability of outer space, processes and materials for biological and nutritional needs of the crew members of long-endurance space flights and space colonies must either be carried aboard the space craft or generated within it. In a closed life-support system, humans would depend upon plants, animals and bacteria to provide food and to recover water and oxygen from waste material (ref. 22). One study (ref. 23) suggests use of agriculture, earth-like but of much higher productivity, as an integral component of space settlement's life-support system. Crops to be raised would represent a conventional selection of plants and meat-bearing mammals and fowl. The culture of algae, once projected as a "space food", is rejected as a major source of nutrition, because of algae's inherent low productivity and lack of attractiveness and variety. The atmosphere would contain carbon dioxide at a partial pressure higher than that on earth, in order to increase agricultural productivity.

The higher levels of productivity required would be attained not only by introduction of modified atmosphere, but also by shortening the growing season, increasing the number of harvests per year, and continued stock and crop improvement. This agricultural effort to facilitate space projects is an illustration of the "role of agricultural technology in aerospace," and thus is the converse of the title of the present report. However, the agricultural solutions needed for carrying out certain space programs probably will provide the impetus for the possibilities mentioned below.

With the advent of the Space Shuttle program, it will be possible to transport materials back and forth between the earth's surface and outer space on a regular basis. This opens the possibility of using certain attributes of the space environment for various agricultural processes. Experiments on genetic alteration of certain species of plants might be efficiently undertaken in a controlled environment set up in space. Also, desirable growth rates or other characteristics might be possible during certain phases of the life cycles of particular species if plants are transported to space for those phases and then returned to earth for subsequent growth and harvest. The space environment can offer zero atmospheric pressure, freedom from pests and contaminants, the possibility of simulating any desired value of gravity, and abundant solar radiation.

8.6 LEGAL PROBLEMS ASSOCIATED WITH AEROSPACE TECHNOLOGY AND AGRICULTURE

The final section provides the technical researcher with an overview of legal problems that affect the application of aerospace technology to agriculture. Discussion is offered on four areas of the law that have had or may be expected to have a significant impact on the development of this technology. No pretense of comprehensiveness is made; rather, we will acquaint the reader with both legal institutions that may be called upon to prohibit or regulate these processes, and legal doctrine that may be applied. The first subsection, "property rights", focuses on the liability problems of the custom applicator andthe farmer than can result from pesticide drift. Next, the federal environment regulatory system will be explored with an emphasis on laws that relate to use of pesticides. The third subsection considers the problems of regulating weather modification attempts, and argues that a coordinated national system is needed. Finally, we will discuss the debate over the legality of remote sensing by satellite. Several nations have taken issue with these activities, and there is a possibility that the United Nations will prohibit such activities without prior consent of the target nations.

PROPERTY RIGHTS: PROBLEM OF PESTICIDE DRIFT

Large-scale farming practices in the United States have created a demand for low cost methods to apply insecticides, pesticides, and herbicides. Modern chemicals conbined with Ag-Air techniques have helped to ease this demand, particularly for such narrow-leafed crops as wheat, corn, and rice. When these chemicals are improperly applied or allowed to drift, they can cause serious damage to neighboring property (ref. 24, p. 816). This section deals with the legal problems engendered by the misapplication of pesticides during Ag-Air operations.

Liability of the Custom Applicator

An individual has the right to apply pesticides and other chemicals to his land. If the individual chooses to hire a custom applicator to perform these functions, then the custom applicator will be liable for damage to neighboring property caused by the drift or atmospheric movement of the applied pseticide. Most courts apply the tort concept of negligence to define the conditions required to hold an operator liable for pesticide drift. To find negligence, the court must determine that the defendant-applicator carried out his operations with an unreasonable disregard for the safety of neighboring property. In making determination, one New Jersey court considered:

1. The likelihood that the act (crop dusting) will cause injury to another,

2. the likelihood that the injury will be serious,

3. the utility of the act itself,

4. the feasibility of a substitution whereby the benefits may be obtained at less hazard (ref. 25).

Past examples where the courts have found negligence include; failure of the applicator to cut off spray valves, spraying on a windy day with knowledge of a pesticide's propensity to drift, and failing to notify adjacent property owners of the intention to spray (ref 24, p. 819).

Three jurisdictions (Oregon, Oklahoma, and Louisiana) have held the ag-operator strictly liable for all damages suffered by third parties as a result of spraying operations. If the operator applied pesticides and the plaintiff can prove that the pesticide caused damages, then the court will award compensation regardless of the operator's lack of fault (ref. 24, p. 819). In an Oregon case, Loe v Lenhardt, (ref. 26), the court addressed issues underlying its decision to impose strict liability on crop dusting activities. Where an acitivity has a high degree of danger, not withstanding the exercise of the utmost care, then the court will impose strict liability - - not for fault, but for the voluntary undertaking of a risk.

Whether an ag-operator should pay for all damages caused by his activities (strict liability), or only those resulting from conduct that can be characterized as negligent, is a decision that involves questions of public policy. Four factors should be weighed in making an evaluation:

1. the effect that the rule of liability will have upon appeasing the vengeful spirit of the injured victim;

2. the social value of having the activity carried on in the community as against prohibiting it;

3. the extent to which the fair and just allocation of accident costs will be facilitated by the rule;

4. the effect the rule will have on deterring risky practices (ref. 24).

Using this framework, it can be predicted that the imposition of strict liability would impede development of the aerial application industry. States choosing to impose strict liability have argued, however, that "fairness requires that one who undertakes an activity beneficial to him should not be allowed to reap the benefits without bearing the cost of losses he may inflict upon another." (ref. 24, p. 823). In contrast, under the more lenient negligence theory, many innocent parties would not be compensated for their losses.

Liability of the Landowner for Negligence of Custom Operator

Generally, an employer is not liable for damages caused by an independent contractor he has hired. The employer is considered to have no real control over his contractor's actions; thus, no moral responsibility for injuries caused by the contractor. Exceptions to the rule have been made, however, where the work contracted for is considered to be inherently or intrinsically dangerous. Many courts have labeled aerial application as exceptionally dangerous and hold the employer-farmer liable for the negligent activities of his custom applicator. In S. A. Gerrard Co. v Fricker, (ref. 27), an Arizona court endorsed this exception pointing out that the farmer should not be able to avoid liability for such dangerous activities simply be delegating the work to an independent contractor. A minority of the jurisdictions have further extended the exception by holding the farmer strictly liable for the activities of his independent contractor. See e.g., Gotreaux v Gary, (ref. 28).

Suggestions for Minimizing Liability Problems

Legal problems in Ag-Air operations could be reduced by the following. First, the operator should obtain up-to-date information on weather conditions--particularly, wind velocity. Second, under current law, an applicator is responsible for knowing the exact nature of the pesticides he is using and the acceptable methods of application. Applicators should therefore be required to periodically attend training sessions to up-grade their knowledge. Third, improved dispersal systems would reduce the dangers of pesticide drift and should, therefore, be a research priority.

REGULATION OF THE ENVIRONMENT

The green revolution has improved food production through improved crop varieties, methods of culture (such as plowing and crop rotation) and effective applications of chemical fertilizers and pesticides. The large increase in production has been primarily due to the extensive application of fertilizers and pesticides by ground and air equipment. It has been estimated that if pesticides were not used, U.S. agricultural production might decline 25% (ref. 29, p. 1). The use of fertilizers and pesticides, however, has contributed to the degradation of the air, land, and water. As a source of pollution, pesticides are of greater concern than fertilizers because of the constant increase in the quantity manufactured and applied, their slow rate of breakdown into harmless compounds, their absorption by man and animals, and their ability to move through and remain suspended in the air (ref. 29, p. 2).

Pollution

There are two sources of air pollution in agricultural areas. Nonpesticidal air pollution is caused by "...windborne dust from land tilling, residues from crop and forest burning, municipal refuse applied to agricultural land, emissions from animal agriculture, and fertilizer application and manufacture... (ref. 30, p. 227). Its major air pollutant is particulate matter which causes "...visibility reduction, soiling of materials, meterological effects, ... and can threaten human and animal health through inhalation" (ref. 30, p. 228). Pesticidal air pollution is caused by the entrance of pesticides into the atmosphere through the application process, wind erosion, volatilization from crops and soil, drift and evaporation, accidental release, evaporation of the liquid carrier, and the manufacturing process (ref. 31, pp 9, 10, 13). Once in the atmosphere, pesticides can translocate from their point of application and fall on distant non-target areas.

Pesticides and fertilizers primarily affect water quality through runoff. Runoff occurs when chemicals are not absorbed by the soil and are washed into water by rain or irrigation. Surface runoff affects open bodies of water in two ways. First, agricultural wastes containing phosphorous, nitrogen, and carbon, which were not absorbed by the soil after application, run off the land. They fertilize the water and increase the aquatic ecosystem's rate of productivity through the process of eutrophication. This leads to the excessive growth of few algae species; particularly the blue-green algae. This algae is poor food source leading to a decline in fish resources (ref. 32, p. 125).

The second way involves the organochlorine pesticides such as DDT and dieldrin. Because of their decay resistant nature, they exist for a long time in the environment and ultimately reach the water. They enter the aquatic environment through the application process, as part of the sediment from leached soil, and surface runoff, and by being removed from the atmosphere by the rain (ref. 33, p. 27). From this point, they enter the food chain affecting animals such as birds and man.

Some organochlorine compounds remain in the soil in unaltered states for long periods of time (ref. 34, pp 78-79), leading to pesticide buildup. This buildup reduces crop yield, contaminates food chain organisms and adjacent nonsprayed soils and water, and may contaminate root or hay crops (ref. 35, p. 323) It also "...creates strains of insecticide resistant insects or results in the elimination of useful insects" (ref. 36, pp 54-55). Frequently, the more active natural predators of a target population will be killed in greater numbers than the target pest. When the target pest regenerates it faces a much reduced predator population (ref. 37, pp 131-132). Subsequent treatments of the pest, therefore, require increased chemical applications. Environmentalist agree that in this sense, insecticides are self-defeating, and urge more flexibility in the treatment of crops for pests (ref. 38, p. 17).

Regulation of Pesticides

The concern over the quality of the environment has brought the passage of legislation and accompanying regulations designed to correct past mistakes. The U.S. with the passage of the National Environmental Policy Act of 1969 and the creation of the Enviromental Protection Agency (EPA) in 1970 has been the world leader in governmental recognition of the need to protect and enhance the environment. Subsequent legislation of the 1970's has further emphasized the national committment to prevent or reduce man's adverse affects upon the enviroment.

The reduction of water pollution caused by agricultural activities is a goal of the Federal Water Pollution Control Act of 1972 (ref. 39, 33 USC 1254 (p)). The Act directs EPA's administrator to establish effluent standards regulating permissable discharges into water by industry and waste treatment plants. Until recently, there were few regulatory restrictions on agricultural discharges into water. EPA will soon be implementing a general permit program to regulate discharges into navigable waters from agricultural point sources (ref. 40). This program will make possible the regulation of pesticide and fertilizer runoffs of individual farmers. This will hopefully reduce the surface runoff problem which adversly affects water quality.

The Food and Drug Administration (FDA) has a minor role in the control of pesticides. To protect the public health, the FDA establishes "...the basic tolerance limits or aceeptable levels for specific chemicals on various produce, including animal products, marketed in the U.S.A." (ref. 41, p. 22; ref. 42, ʃʃ 342, 346).

The environmental Protection Agency through the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) (ref. 43) has responsiblity for controlling the use of pesticides. A substance is a pestcide if it is intended to prevent, destroy, repell, or migrate any pest, or is a desicant (ref. 44, 162.3ff). Fertilizers and plant nutrients per se are not pesticides (ref. 44, 162.4 (c)5). The provisions of FIFRA and its accompanying regulations must be adhered to by any applicator of pesticides.

Registration of Pesticides

FIFRA requires the registration or reregistration and classification of pesticides with the EPA before they may be used (ref. 44, part 162.2). The reregistration process applies to all pesticides existing prior to October 1977. It involves 33,000 products and the EPA is now existing products is valid data supplied by the Department of Agrciulture on existing products is valid (ref. 45, p. 1,742). If it is determined the data is inadequate, restesting will have to occur before the products may be reregistered.

Registration is done on a use by use basis with denial to those uses which create the most danger (ref. 46, p. 218). FIFRA essentially require that proof be given that the pesticide is within FIFRA's guidelines and will not unreasonably harm the environment (ref. 44, part 162.2 (d)). The applicant wishing to register a pesticide has to submit supporting data according to guidelines issued by EPA's Administrator (ref. 44, part 162.6 (b) (2) (B), 162.8). These guidelines require the submission of data measuring a pesticide's toxic effects on surrounding plants and animals and its hazard to non-target organisms (including human, domestic and wild animals). The burden of proof as to the pesticide's safety is upon the applicant thereby creating a rebuttal presumption against registration (ref. 44, part 162.11a (3) (4)). It has been estimated that the registration process will range from a minimum of 5 years to a maximum of 15 years (ref. 45, p. 1,742). Once a pesticide has been registered the registration will be cancelled 5 years after the registration date unless the registrant requests it to continue (ref. 44, part 162.6(c)).

There are exemptions from the registration process. An experimental use permit may be issued, (ref. 44, part 162.5(b), 162.2, part 172) and there may be emergency exemptions for federal and state agencies (ref. 44, part 162.5 (b) (5). The EPA will also allow states to register new pesticides for special local needs (ref. 47, p. 1,417).

As part of the registration process, pesticides are to be classified for general or restricted uses, or the same pesticide may be classified for general use in some instances and restricted in others (ref. 44, part 162.2(c)). A pesticide will be classified for general use if when used correctly, it will not generally cause unreasonable adverse effects on the environment (ref. 44, part 162.2c (1)). It will be classified as restricted if, when applied without additional regulatory restrictions, it may cause unreasonable harm to the environment or the applicator (ref. 44, part 162.2 (c) (1)). The direct supervision of a certified applicator is required if a pesticide is classified as restricted (ref. 44, part 162.2(c) (2) & (3)).

At present, if the EPA determines a pesticide presents an environmental danger, three means of removal exist. Registration of the pesticide can be denied, it can be classified only for restricted uses, or the registration can be suspended or cancelled (ref. 46, p. 219).

Regulation of Aerial Application

The EPA in May 1977 issued Pesticide Enforcement Policy Statement VII (PEPS) to explain how it would enforce FIFRA with particular reference to aerial application. The policy "...applies to the use of registered pesticides in agricultural applications for the agricultural crops, in forest pest control, in ornamental turf pest control, in right of way pest control, and in public health and regulatory pest control (ref. 48, p. 13). A registered pesticide may be applied aerially only if it is affirmatively stated on the pesticide's EPA accepted label (ref. 48, p. 26). There exist civil and criminal penalties for misuse.

A state may place additional restrictions on the use of a federally registered product (ref. 48, p. 26). Under FIFRA, each state will have a "State Control Agency" to regulate pesticide use (ref. 48, p. 32 & ref. 6, part 171). The EPA is providing grants to states to enable them to help the EPA enforce FIFRA (ref. 47, p. 608).

The PEPS places pesticides into six categories. The label instructions on each pesticide will indicate its category. Pesticides in categories I, V, and VI may be aerially applied so long as the appropriate instructions and safeguards are followed (ref. 48, pp 27-28). The applicator has the burden of proof to show that the criteria have been met, and he is normally held liable for damages.

Aerial application of pesticides in categories I, V, and VI may be done only after a written recommendation of knowledgeable expert with appropriate education and experience has been submitted (ref. 48, pp 29-30) to the State Control Agency. The recommendation is valid only in the states where it is made, and it may be relied upon by other state applicators under similar circumstances. It is to specify "...the pesticide, ...the geographic location,... the commodity,...the pest to be controlled, and the...duration for which the recommendation is applicable...(it must include) all appropriate instructions regarding dilution rate, mixing and loading method, aerial applicator equipment to be used...pesticide drift, and environmental or ecological precautions... (ref. 48, p. 28). The recommendation is to be forwarded to the State Control Agency before application (ref. 48, p. 32).

Federal regulations also provide worker protection standards for hand labor operations after any pesticide application. The regulations require clearing of the area of unauthorized individuals before spraying (ref. 44, part 170.3(a)), state re-entry times before a worker without protective clothing may enter a treated field (ref. 44, part 170.3(b)), and require strict adherence to labels on pesticides (ref. 44, part 170.4). The worker is to be warned of the presence or use of pesticides (ref. 44, part 170.5).

The EPA has responsibility for establishing minimum requirements for registration, classification, and use of pesticides. These requirements are to be placed upon labels and strictly followed by the applicator. A state may impose stricter requirements and controls on pesticide use.

Recommendations

There are several areas which should be investigated in attempts to reduce pollution and protect the environment:

1. EFFORT SHOULD BE MADE TO DEVELOP ECOLOGICALLY SELECTIVE PESTICIDES. The primary pesticides in use today are the organo-phosphates which are highly toxic and short lived. Their short life requires them to be frequently applied with the resultant destruction of many friendly insects.

2. INVESTIGATION SHOULD BE MADE INTO WAYS TO MONITOR THE WIND, TEMPERATURE, AND HUMIDITY OF INDIVIDUAL FIELDS TO AVOID SPRAYING WHEN CONDITIONS FAVOR PESTICIDAL DRIFT AND/OR VOLATILIZATION.

3. BETTER SPRAY EQUIPMENT IS NEEDE TO INSURE PROPER APPLICATION. Equipment improvement would reduce the chances of the application of high chemical concentrations and dripping which could cause stunted plant growth. It would also serve to reduce the amount subject to runoff thus protecting water quality.

4. WE SHOULD DETERMINE WAYS TO REDUCE THE EXPOSURE OF AG PILOTS AND THEIR GROUND CREW TO PESTICIDES. This could be done by providing methods of fast loading and sealing methods to prevent leaks. Pilot and flagmen exposure could be reduced by careful plotting of the flight pattern to avoid drift. Some authomatic method of telling the pilot where his next swath should be would eliminate much of the risk of exposure.

5. MORE USE SHOULD BE MADE OF THE CAPABILITIES OF REMOTE SENSING TO DETECT EROSION, AND PESTICIDE AND FERTILIZER RUNOFF INTO WATER. In a monitoring experiment, aircraft and LANDSAT were used to measure chlorophyll a concentrations and suspended sediment in the water. Chlorophyll a concentrations are a measure of the nutrient loads and current health state of the water (ref. 49, pp 1-2). Abnormally high or low concentrations of chlorophyll a could indicate pollutant inputs and/or effects (ref. 50). This information could be used to develop indicators defining acceptable levels of discharges into the water (ref. 48, p. 26). High sediment levels in the water were found to be measurable and could be used to detect erosion of nearby land. Both measurements could indicate whether agriculture and/or industry are adversely affecting water quality. The following is an example of how remote sensing information may be used to lessen water pollution. Section 208 of the FWPCA "...provides fund for developing a water management paln navigable streams in areas of serious urban and industrial pollution..." (ref 51, p. 46). Toledo, Ohio used infrared photography from aircraft to pinpoint stream pollution caused by soil, fertilizer, and nutrients draining into the water. It did this by combining the photography with land use data to discover the source of the pollution. With this information, Toledo officials could then contact the farmers, inform them of the problem, and suggest that corrections be taken (ref. 51, pp 46-47).

6. STRICTER FEDERAL REGULATIONS ARE NEEDED TO CONTROL THE MARKETING OF PESTICIDES. Present regulations are inadequate to control pesticidal air pollution as they do not provide an adequate mechanism for preventing the registration and sale of pesticides which are potential sources of harmful air emissions. The risk criteria adopted by the EPA fails to address potential pesticidal air pollution except by those pesticides having either a relatively high acute inhalation toxicity or producing adverse chronic effects in experimental animals (ref. 46, p. 219). "None of the cancellation or suspension, proceedings initiated by EPA... have focused on pesticidal air pollution" (ref. 46, p. 221). To correct this shortcoming, adequate data is needed to develop standards to measure such matters as the "concetration of pesticides in the ambient air and the toxicological effects caused by inhalation of...pesticides" (ref. 46, p. 218). The data would provide information to determine which pesticides present a plolution danger and which do not. It is possible the data may show that pesticidal air pollution is not dangerous enough to be concerned with. Some kind of sensor would be needed to measure the presence and movement of pesticides through the air so that informed decisions could be made as to the need for correcting regulations.

WEATHER MODIFICATION

Weather modification is a process whereby man attempts to alter the climatic conditions of his environment. It is not a new phenemenona; indeed, man from prehistoric time onward has uttered chants, cast spells and thrown magic powders skyward in an attempt to induce rainfall from the Gods. Like these earlier efforts, many of man's more recent attempts also have failed to produce their intended results. In 1947, General Electric seeded an Atlantic hurricane off the coast of Florida as part of Project Cirrus, a private hurricane modification experiment. The hurricane, rather than diminishing in force as expected, erratically veered westward pummeling the Florida, Georgia, and South Carolina coasts with high winds and rain, and caused nearly five million dollars in damage (ref. 52, p. 540, ref. 53). This section examines the attempts made by courts and legislatures to regulate weather modification activities, and to compensate persons injured as a result of experimentation in this field.

Neither the state or federal courts nor their legislatures have offered a coherent approach to the regulation of weather modification. Since large scale attempts to alter the environment are still uncommon, it has been difficult to strike a balance between potential harms and potential benefits to society. Authorities even disagree on which acitivities constitute weather modification. The State of Washington, for example, limits the definition of weather modification to those attempts designed to alter the natural development of clouds (ref. 54). Alternately, the Congress has considered a broader definition which includes all operations to purposely change atmospheric conditions, "operations designed to increase precipitation, decrease precipitation, suppress hail, suppress lightning, dissipate fog, and suppress or divert storm systems." (ref. 55). At present, the Congress has not attempted to control weather modification acitivities, although it requires that these activities be reported. Individual state governments, through their courts and legislatures, are free to regulate weather modification and to provide compensation to injured parties.

Judicial Control of Weather Modification

Since weather modification activities ultimately affect individual property owners, one possible means to control such experiments is to allow damaged parties to present their claims in a court of law. Judicial oversight would appear to be an effective regulatory technique; it forces experimenters to pay for damages caused through recklessness or haphazard practices. Obviously, the damaged property owner would have sufficient financial incentive to bring suit.

Court litigation, however, has not proven to be a useful technique for the regulation of weather modification. On one hand, suits against government agencies for damages caused by their experimental programs are rarely entertained because the government can claim an immunity for its actions under the Federal Tort Claims Act (ref. 56). On the other hand, civil suits against private operators seldom succeed because the injured plaintiff cannot prove that the weather modifying acitivites directly caused their damages.

In one case, Adams v California, (ref. 57), plaintiffs alleged that cloud seeding activities of North American Weather Consultants culminated in an excessive rainfall flooding Yuba City. The flood caused 64 deaths, and millions of dollars in property damages. The plaintiff's, however, lost the suit because they were unable to prove beyond a reasonable doubt that the defendant's activities actually caused the excessive rainfall. North American's experts successfully argued that their operations had no real effect on the amount of rainfall, although, ironically, they had been advertising a twenty percent increase in rainfall until the flood (ref. 58).

If it were possible for a plaintiff to establish in court that weather modification operations actually caused damages, a court could choose to impose liability against the weather modifyer for negligence or, instead, hold the operator strictly liable for his acitivities. For the court to find negligence, the plaintiff must show that the defendant operator acted in a manner inconsistent with normal standards for weather modification activities. Such standards would be difficult to define, however, because normal practices for weather modification have not yet been established. Strict liability, a means of imposing liability regardless of fault, may be a possible alternative here. As a rule, courts impose strict liability only in excptional cases where an individual's activities are abnormally dangerous despite all precautions (ref.59, pp 139-204). Since weather modification is inherently dangerous, and results cannot always be limited or controlled the court should consider placing it in this category. This has been the conclusion of a number of authorities studying the problem (ref. 53, ref. 58).

Legislative Control of Weather Modification

In at least 31 states, legislatures, have either required the courts to follow statutory guidelines controlling weather modification, or have charged an administrative agency with regulating the activity (ref. 60, p. 415). Stautory approaches have varied; some states have attempted to comprehensively regulate all phases of environmental interference, (ref. 61) others, only require licensing of the chosen activity (ref. 62). A number of states have created regulatory agencies to control weather modification. These bodies offer flexibility and expertise while minimizing the need for rigid legislative. codes. Commentary to an Illinois statue explains the advantages of the regulatory agency (ref. 63):

> It is not the intent of this act to spell out in detail the weather modification control procedures and criteria for the state. Weather management technology is rapidly developing. It is not now possible to forsee all of the regulatory problem that will be associated with it. The necessary flexibility for control over the field can best be provided by setting forth the basic regulatory structure in the act and authrizing the Department of Registration and Education to fill in the gaps by use of its powers to make reasonable rules and refulations.

Using this approach, it becomes the legislature's job to spell out the criteria upon which the regulatory board must base its decisions. Before allowing a weather modifying operation, the board should investigate and evaluate whether:

A. The applicant is qualified to undertake the weather modification operation proposed in his application;

B. The production, management or conservation of water or other resources or agricultural or forest crops could be benefited by the proposed weather modification operation; and

C. The proposed weather modification operation would not be injurious to the public health or safety.

As states develop regulatory policy for weather modification, these criteria should be minimal considerations for licensing.

The federal government has taken steps to monitor weather modification activities. In 1971, the President signed into law a reporting requirement bill for weather modification acitivities (ref. 64). The law requires that all persons engaging in weather modification activities in the United States submit reports of their experiments to the Secretary of Commerce. For a willful violation of this requirement, the penalty can be as high as $10,000 (ref. 64, sec. 5). At best, however, the Act merely provides for federal monitoring; it does not attempt to regulate the acitivities.

Future Considerations for a Weather Modification Policy

While weather modification efforts have not been extensive in the past, it appears that the advances in technology will prompt increased activities in the future. Dr. Wehrner Von Braun has predicted that within the next 25 years man will be able to control weather and atmospheric conditions to the extent that a particular location can have sun all day and rain all night (ref. 65). But even accepting a more conservative scenerio, there are ample reasons for the federal government to begin fashioning a comprehensive weather modification policy.

First, as operations icrease, it will quickly become apparent that the damages resulting from accidents will be regional rather than be confined to one state. When Washington seeds clouds to improve the snow pack for its winter resorts, it consequently appropriates rainfall that would normally fall in Idaho. Neither state can fairly determine who deserves the rain; a national scheme is required. Many commentators have gone further to suggest that the problem is international rather than merely national in its scope. Nations, they argue, must accept world-wide responsibility for their weather modification efforts (ref. 53, p. 414).

Growing concern for the environment provides a second reason for national attention. Again, ecological systems know no state boundaries. The federal government has taken its first steps to recognize the problem with the Environmental Policy Act of 1969. It requires that federal activities which "significantly affect the quality of the human environment" shall not proceed until an acceoptable environmental impact statement has been filed (ref. 66). Federal agencies with environmental management programs have recently begun to file these reports, (ref. 60, p. 438) however, the Act does not cover operations by state and private organizations. Furthermore, the Act is targeted toward recording the activities of federal agencies, rather than coordinating their experiments in a coherent fashion. As weather modification programs gain widespread acceptance, such coordination on a national level will become a necessity.

REMOTE SENSING

While man does not yet possess the capability to monitor the activities of an individual through orbiting space stations, his present ability to survey world resources by remote sensing has prompted some nations to claim violations in their right to privacy. On their face, the charges are plausible; remote sensing by definition is "a methodology to assist in characterizing the nature and condition of the natural resources, natural features and phenomena, and the enviorment of the earth by means of observations and measurement from space platforms." (ref. 67, p. 12). Other nations, however, have advanced the position that outer space is open territory and, since remote sensing units function extra-terrestrially, their information is taken free of claims for national privacy. As present, international law is silent respecting this conflict. This section examines various proposals made for an international law om remote sensing.

Legal Basis for Remote Sensing: The Present State

Before the first remote sensors were launched into orbit, legal theorists debated whether the doctrine of sovereign airspace applied to the outer reaches of space. By international agreement, no nation may conduct activities which encraoch upon a neighboring state's airspace without that nation's express consent; remote sensing be airplane or balloon clearly fits into this category (ref. 68, p. 23). Accordingly, when the United States and the Soviet Union orbited satellites, each announced its intentions well in advance of the launching (ref. 69). Later, when the sensing operations were questioned, legal commentators pointed to the lack of objection at launch time as evidence of an implied consent by the sensed nations.

The United Staes maintains that no provision of international law restricts or inhibits remote sensing from outer space (ref. 70, p. 94). A task force from the United Nations also surveyed existing international agreements and concluded that:

> There does not appear to be any principle or rule of international law as it now stands that makes it unlawful for a country to freely observe everything and anything it regards worth observing in another country, so long as it carries out its observations from beyond the limits of national sovereignity (ref. 67).

The debate over remote sensing has centered upon differing interpretations of national sovereignity.

By the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (outer Space Treaty) (ref. 71), signatories limited their national soverignity to controlled lands, territorial waters and the atmosphere above them. Article I specifically proclaims that "Outer space...shall be free for exploration and use by all states without discrimination of any kind..." Thus, the treaty, while not stipulating remote sensing, has been cited for the proposition that sensing acitivities transcend claims of sovereignity.

There are authorities, however, who question this interpretation. Reijnen distinguished remote sensing from those activities considered in the Outer Space Treaty. Remote sensing, he argued, differed from activities taking place in outer space because "they are exclusively (his emphasis) of direct (his) interest to Earthian development." (ref. 68, p. 22). As Dr. H. P. Heere put it:

> Earth resources is a terrestrial matter, and should as such fall under terrestrial law, not space law. The interests of mankind may perhaps not be identical with those of space industries... (ref. 68, p. 22).

The Soviet Union also takes this position. Vereshchetin, speaking for Soviet lawyers on the point, emphasized that:

> Freedom of exploration and use of space generally and particularly in the case when the object of researching is not space itself, but sovereign territories on the earth, sensed by space means, is not to be in any way opposed to the principle of state sovereignity and all the more, dominate it." (ref. 72, p. 127).

Ultimately then, disagreement over legal status of remote sensing revloves around the right to privacy from the spying eye in outer space. Satellite sensing systems, although operating exclusively in outer space, conflict with the "inherent and absolute right of states to dispose of their national resources and information on these resources." (ref. 72, p. 127).

Future Policy for Remote Sensing: An International Perspective

Despite potential disagreement over proposed texts, a majority of nations have indicated that some form of international regulation should be developed for remote sensing (ref. 73, p. 329). A legal subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space has been working since 1974 to draft such a document. Five principles (summarized here) have been accepted provisionally by the group:

1. Remote sensing should be carried out for the benefit of all countries regardless of economic or scientific development.

2. Remote sensing should be conducted in accordance with international law.

3. Sensing states should make opportunities for participation available to other states.

4. Remote sensing should promote protection of the Earth's environment.

5. Sensing states should supply technical assistance to other interested states on mutually agreed terms (ref. 70, p. 94).

The subcommittee, however, has not reached the consensus that international law should impose restrictions on a nation's ability to sense and disseminate information freely. A working document presented jointly by France and the Soviet Union expressly urged the United Nations to sanction an international right to privacy. Article four provided that:

A state which obtains information concerning the national resources of another state as a result of remote sensing activities shall not be entitled to make it public without the clearly expressed consent of the state to which the national resources belong to our use it in any other manner to the detriment of such state (ref. 72, p. 128).

The United States proposal took the position; while remote sensing must conform to the principles of the United Nations Charter, the Outer Space Treaty and other accepted principles of international law, "prior consent" rules are counterproductive to the interests of the world (ref. 73, p. 334).

In the near future, the United Nations must attempt to reconcile these differences and fashion a coherent policy for remote sensing. If the United Nations extends the liberty principle, espoused by the West, to remote sensing, then the United Nations must take steps to ally fears of exploitation. Many non-western nations have expressed apprehension that in the absence of control over dissemination of remote sensing data, the large multi-national corporations could use the information for making economic prognoses in different branches of the world economy. Thus, they could determine the most profitable fields of capital investment, and dictate their own conditions for resource development (ref. 74, p. 242).

Widespread dissemination of all remote sensing information may be an answer to this problem. To the extent that all interested parties have the benefits for similar information, opportunities for exploitation would diminish. This would be consistent with present United States policy. The National Aeronautics and Space Administration Act of 1958 required that activities in space contribute materially towards advancing international cooperation (ref. 75). In accordance with this policy, NASA has encouraged some 50 countires, and two international organizations to participate in the LANDSAT pictures (ref. 73, p. 327). Regional ground stations are also being constructed world-wide. Their data will be accessible to all nations.

Whether such a compromise can be reached is still an open question. Proponents both for free space and for national privacy have legitimate interests that both feel must be protected. Such interests conflict, however, and eventually must be reconciled. Given the rapidly improving technical capability for remote sensing, and the benefits of established systems, it is likely that remote sensing acitivities will increase, rather than decrease, in the future.

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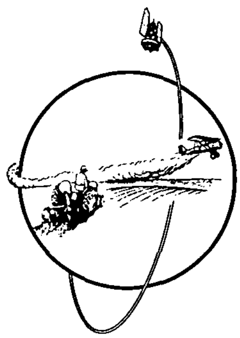
PART III



APPENDICES

APPENDIX A

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The Design Team found the materials listed in this bibliography useful in providing background knowledge in the field of the study. These materials are in addition to the reference cited at the end of each chapter.

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APPENDIX B

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APPENDIX C

GUEST LECTURERS

Date	Speaker/Affiliation/Topic
June 6	Bruce Holmes NASA-Langley Research Center "Overview of Agriculture - Aircraft Research"
June 13	Errett Deck U.S. Department of Agriculture, Washington, DC "Activities of the Department of Agriculture"
June 13 & 14	Kenneth Razak Consulting Engineer, Wichita, KS "Aerial Applications Operations and "Ag-Plane Design"
June 14	Carl F. Zorowski North Carolina State University, Raleigh, NC "Engineering Systems Design"
June 16	William Holmberg Environmental Protection Agency, Washington, DC Seminar on Pesticide Usage in Agriculture
June 20	Norman Foster NASA - Johnson Space Flight Center, Houston, TX "Remote Sensing Systems"
June 20	Ruth Whittman NASA Headquarters, Washington, DC "LANDSAT and LACIE"
June 20	Charles E. Olson, Jr. University of Michigan School of Natural Resources, Ann Arbor, MI "Remote Sensing - Forests"
June 23	B. Jack Butler University of Illinois, Urbana, IL "Ground Application of Chemicals"
June 23	Barry Jacobsen University of Illinois, Urbana, IL "Plant Pathology"

Date	Speaker/Affiliation/Topic
June 23	F. Farrell Higbee National Agricultural Association, Washington, DC "Ag-Plane Operations"
June 27	John Rehder University of Tennessee, Knoxville, TN Seminar on Remote Sensing
June 28	Norman B. Akesson University of California at Davis, CA "Aerial Applications"
July 6	Klaus Heiss ECON, Princeton, NJ "Economic Analysis of Remote Sensing Operations"
July 12	Bruce Holmes NASA-Langley Research Center "Training Ag-Pilots"
July 13	A. J. Provenzano Old Dominion University, Norfolk, VA "The Ocean as a Food Resource"
July 14	Jack Ellis CIBA-GEIGY, Greensboro, NC "Future in Agricultural Chemicals"
July 21	H. Spencer Potter Michigan State University, E. Lansing, MI "Plant Pathology and Aerial Application"
July 22	Bruce Holmes NASA-Langley Research Center "NASA Aerial Applications Technology Review"
July 25	Frank Jordan NASA-Langley Research Center "Aerial Application Research in the Vortex Research Facility"
July 28	Dana Morris NASA-Langley Research Center "Computer Modeling of Aircraft Wake Flow Field"
August 3	LTC G. S. Rowcliffe, LTC L. W. Trager, Jr. and LTC D. L. Snyder 355th T.A.S. Rickenbacker Air Force Base, OH "Large Scale Spraying for Insect Control"

APPENDIX D

ACKNOWLEDGEMENTS

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APPENDIX E

ORGANIZATION OF THE DESIGN TEAM

A. Preliminary Study

Initial effort of the team was directed toward formulation of goals and objectives of the study. The participants were divided into four groups, each of whom studied, debated and recommended goals and objectives of the design study. These initial groups were:

Group 1	Group 2
V. E. Delnore, Chairman	R. D. Sylvia, Chairman
R. Benumof	E. Maier
D. J. Bayles	J. Kirkpatrick
F. M. Slapar	M. S. Dallal
W. J. Boyer	J. C. Tredennick

Group 3	Group 4
R. T. Tsuchigane, Chairman	J. B. Rehder, Chairman
T. F. Redick	J. M. Klosky
R. K. Shepler	P. C. Heckert
D. T. Higgins	J. G. Eisley
	D. E. Holzhei

These groups worked independently and finally came together to reach a consensus on a goal statement. After the overall goal had been spelled out, further meetings of the separate groups were held, during which time efforts to develop an analytical description of the system were made. In general session the system model which is described in Chapter 1 was developed. Once this framework was established the in-depth study was begun.

B. In-Depth Study

Following three weeks of preliminary investigation, the group was reorganized to carry out the main study and to prepare the report. The organization consisted of four Task Forces (X groups) corresponding to the four major divisions of the problem. In addition, each participant was also a member of a Technology Group and of a "Systemic" Group.

This organization was designed to assure that a true "systems" viewpoint was maintained throughout the study period. It seemed obvious that, should the organization consist solely of the four task groups, there would be danger of developing insular views of the task at hand. To preclude such a trend an interlocking organization was developed. The structure was designed to implement communication among task groups while, at the same time, providing an overview in certain areas considered important. The technology (Y) groups were formed for several purposes:

1. To pool expertise in specific areas of technology to provide an identifiable source of information.

2. To prevent redundant efforts in different task groups when the same technology is being applied to different system functions.

3. To assure that ideas produced in one task group become available to other groups as appropriate.

The systemic (Z) groups were formed to play a somewhat different role. The first three were designed as "watch dog" groups to act as guardians assuring that their areas of interest were given sufficient and system-wide consideration. For instance, the Z-2 group was to see that not only would the efficient use of energy resources be given proper emphasis for each technology application, but that the total system design would be energy efficient. The Z-4 group was assigned the job of gathering together the task group developments which would, in the conglomerate, facilitate planning in agriculture. It was felt that the planning function in agriculture was important enough to receive this organizational emphasis. The result of this group's efforts was to be manifested in an overall scheme which would facilitate planning through the application of technology.

The function of group Z-5 was to assure a high-quality and unified report. The oral presentation committee put together the presentation given at the end of the study period. The reader will note that each task group (X) had representation on each of the Y and Z groups giving every opportunity for the desired interchanges. The assignments were:

TASK FORCES:

X1. Plant and Animal Culture

J. G. Eisley, Chairman
F. M. Slapar
D. E. Holzhei
R. D. Sylvia
M. H. Snyder

X2. Environment & Resources

J. B. Rehder, Chairman
J. M. Klosky
R. Benumof
W. J. Boyer
J. Kirkpatrick

X3. Support Services

D. J. Bayles, Chairman
M. S. Dallal
V. E. Delnore
R. T. Tsuchigane
D. T. Higgins

X4. Socio-Cultural Interactions

E. Maier, Chairman
R. K. Shepler
P. C. Heckert
T. F. Redick
J. C. Tredennick

TECHNOLOGY GROUPS:

Y1. Remote Sensing Systems

D. E. Holzhei
J. B. Rehder
R. T. Tsuchigane
T. F. Redick

Y2. Airframe, Airfoil & Propulsion

J. C. Tredennick
M. S. Dallal
J. Kirkpatrick
M. H. Snyder

Y3. Information Systems

R. D. Sylvia
J. M. Klosky
D. T. Higgins
E. Maier

Y4. Material Dispersal Systems

P. C. Heckert
D. J. Bayles
W. J. Boyer
F. M. Slapar

Y5. Navigation, Guidance & Control Systems

J. G. Eisley
R. Benumof
V. E. Delnore
R. K. Shepler

SYSTEMIC GROUPS:

Z1. Physical Environment

F. M. Slapar
W. J. Boyer
V. E. Delnore
R. K. Shepler

Z2. Utilization of Energy Resources

T. F. Redick
M. S. Dallal
J. Kirkpatrick
J. G. Eisley

Z3. Social Environment

R. D. Sylvia
J. B. Rehder
R. T. Tsuchigane
J. C. Tredennick

Z4. Planning

E. Maier
D. J. Bayles
J. M. Klosky
D. E. Holzhei

OTHER COMMITTEES:

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R. Benumof
D. T. Higgins
P. C. Heckert

Oral Presentation Committee

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APPENDIX F

SELECTED UNITS AND CONVERSION FACTORS

Symbol	Name	Type of Measure and Equivalence
		S. I. UNITS
m	meter	length, 1 m = 3.28 ft
kg	kilogram	mass, 1 kg = 2.2046 lbm
s	second	time
K	kelvin	thermodynamic (absolute) temperature
N	newton	force, 1 N = 1 kg-m/s^2 = 0.2248 lbf
Pa	pascal	pressure, 1 Pa = 1 N/m^2 = 3.007 psi = 0.02088 lb/ft^2
J	joule	energy, 1 J = 1 N-m = 0.7375 ft-lb
W	watt	power, 1 W = 1 J/s = 0.7376 ft-lb/s = 3.413 Btu
		OTHER UNITS
ft	feet	length, 1 ft = 0.3048 m
mi	mile	length, 1 mi = 5280 ft = 1609 m
nm	nautical mile	length, 1 nm = 6076 ft = 1852 m
μm	micron micrometer	length, 1 μm = 10^{-6}m
	acre	area, 1 acre = 43560 sq. ft = 4047 sq. m
	hectare	area, 1 hectare = 10000 sq. m = 2.47 acre
	section	area, 1 section = 1 sq. mi = 640 acres
bu	bushel	volume, 1 bu = 0.03524 cu. m = 1.244 cu. ft
gal	gallon	volume, 1 gal = 0.003785 cu. m = 0.13368 cu. ft
lbm	pound (mass)	mass, 1 lbm = 0.4536 kg
	ton	mass, 1 ton = 907.2 kg = 2000 lbm
	metric ton	mass, 1 metric ton = 10000 kg = 2204.6 lbm
Atm	atmosphere	pressure, 1 Atm = 1.01325 Pa = 2116.2 lb/sq. ft
lbf	pound (force)	force, 1 lbf = 4.4482 N
Btu	British thermal unit	energy, 1 Btu = 1054.8 J = 778 ft-lb
cal	calories	energy, 1 cal = 4.186 J = 0.0039685 Btu
Cal	large calorie	energy content of food, 1 Cal = 1000 cal (sometimes called a kilocalorie)
ft-lb	foot-pound	energy, 1 ft-lb = 1.3558 J = 3.995 x 10^{-5} Btu
hp	horsepower	power, 1 hp = 745.7 W = 2545 Btu = 550 ft-lb/s
mph	miles per hour	velocity, 1 mph = 0.447 m/sec = 1.46667 ft/s
	knots	velocity, 1 knot = 0.514 m/sec = 1.69 ft/s

A bushel of wheat weighs 60 lb; there are 36.7 bushels in a metric ton of wheat.

NASA-Langley, 1977