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Identification of High Payoff Research for More Efficient Applicator Helicopters in Agriculture and Forestry

by

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ABSTRACT

This report documents the results of a study of the uses of helicopters in agriculture and forestry in the United States. Comparisons with ag airplanes are made in terms of costs of aerial application to the growers. An analysis of cost drivers and potential improvements to helicopters that will lower costs is presented. Future trends are discussed, and recommendations for research are outlined. Operational safety hazards and accident records are examined, and problem areas are identified. Areas where research and development are needed to provide opportunities for lowering costs while increasing productivity are analyzed.

FOREWORD

This report was prepared by the Boeing Vertol Company for the National Aeronautics and Space Administration, Ames Research Center for Helicopter Technology, Moffett Field, California 94035, under Contract NAS2-10046. William Snyder was NASA technical monitor for this work. The Boeing Vertol Company Project Manager was Kenneth T. Waters.

Dr. Bruce Holmes of NASA Langley assisted in this study by providing the author with reports and data on ag-airplane research on-going at Langley and advice on cost benefits analyses. Mr. David J. Marvin of the Boeing Vertol Company assisted in conducting operator interviews and data analysis for the report. Mr. W. Z. Stepniewski, now retired from the Boeing Vertol Company, provided the translation of Russian ag helicopter analyses appearing in Appendix A. Mr. Serge Taptykoff of the Boeing Vertol Company Safety Analysis Group developed the statistical summary charts and accident causal-factor analyses.

SUMMARY

This study was conducted to identify research and development needs to make helicopters more productive and reduce costs of aerial application in agriculture and forestry. Approximately $100 million is spent annually in the U.S. on aerial application by about 900 helicopters. This represents about 10 percent of the aerial application work, while the remaining 90 percent is applied by airplane. Most of the helicopters are small, and at present most are used on smaller, more difficult terrain with wire, pole and tree obstacles, and on orchards and citrus groves where the rotor downwash agitates the foliage at slow speeds for better coverage than can be achieved by airplane. Costs of application are higher with helicopters in general because of the unique capabilities and special uses. However, in some applications where airplanes and helicopters are competing on identical fields the costs are nearly the same. The airplane has the advantage of lower direct operating costs and lower acquisition costs. The helicopter can operate from nurse trucks along side the field, has 1/3 the turn time, is quickly convertible for other uses, and can take advantage of higher utilization and off-season work, which brings application costs down. A number of operators are using both helicopters and airplanes, but in most cases are selecting the aircraft (helicopter or airplane) depending on field size, terrain, obstacles, application rate, and type of material being applied. In general, the helicopter is not considered to be as cost effective in applying dry materials particularly at high rates where small helicopters are not as productive. In forestry, however, larger helicopters are being used for their unique capabilities.

Productivity, in acres treated per flight hour, is most sensitive to swath width, speed, turn time, and distance from the loading point to the field. As application rates go up, the smaller, low-payload helicopters suffer from more frequent trips to and from the loading point. Therefore, the larger aircraft now entering the field are demonstrating higher productivity, and new uses for helicopters are evolving.

The trend to high-rate application of dry granular fertilizers for both agriculture and forestry will bring larger, high payload, higher speed helicopters into the aerial-application field. The use of dry-chemical slingers capable of over 200-foot swath widths and speeds of 80 to 100 mph are state-of-the-art today and will tax the capabilities of ground loading equipment. The fact that comparable swath widths being achieved by airplanes in the U.S. are only 40 to 60 feet combined with the airplane limitations in steep forest terrain will promote use of larger helicopters. The problem of higher acquisition costs and direct operating costs for helicopters can be overcome by high utilization through off-season work.

The accident record shows that helicopters have greater than two times the airplane accident rate in aerial applications which is probably an indication of the rotor causing substantial damage even in minor accidents. Fatal accident rates are about equal, which shows that helicopter accidents are more survivable. The major causes of helicopter accidents are: (1) flying

into wires, poles, and trees; (2) reciprocating engine failures; (3) "failed to maintain rotor rpm"; (4) fuel system failures and contamination; (5) "misjudged speed and altitude"; (6) rotor and drive system failure; and (7) fuel exhaustion. Many of these accidents would not have occurred if reliable engines with greater power margins were installed. The trend toward turbine-engine power should greatly reduce accident rates, but many operators are reluctant to use turbine helicopters because of the higher initial cost.

As a result of this study the following research and development needs in agricultural helicopters for aerial applications have been identified:

1. Develop a better understanding of rotor downwash characteristics and influence on various types of field crops, row crops, orchards, citrus groves and forests. The objective would be to determine maximum practical swath widths and speeds while maintaining material coverage uniformity for a variety of dry and liquid materials, as a function of rotor disc loading, spraying height, spray boom arrangements, and slinger/spreader design parameters.

2. Develop efficient dry-materials spreaders for helicopters with particular attention to fertilizer applications at high rates for forestry and field crops and for seeding of field crops, grasses and forests.

3. Improve performance to increase payload-to-empty-weight ratio.

4. Reduce costs of turbine engines with improved reliability and low specific fuel consumption.

5. Improve safety by reducing accident rates to 1/3 of the current rates and reducing fatalities and injuries by installation of crashworthy features. Most of the required crashworthiness technology is available but has not been applied to agricultural helicopters.

6. Further development and evaluation of low-cost precision navigation systems to improve accuracy of aerial application on forests and large agricultural fields.

7. Take steps to educate pilots in pilot error problems and precautions to prevent excessive fatigue.

8. Develop a cost-benefit analysis model to evaluate helicopter design and operational features and performance capability.

A number of existing features should be designed into agricultural and forestry helicopters. These are listed below:

a. Wire cutters and deflectors for windshields, rotor heads, and landing gear; damage-tolerant main and tail rotor blade tips.

b. Internal hoppers and streamlined external spray and dispersion equipment to reduce drag.

c. Reliable engines with substantial increases in power margin for hot day, altitude operation under the end-of-field turnaround condition.

d. Design special seating, controls, and bubble canopies to make the pilot's job as easy as possible in logging operations.

e. Provide cockpit air filtration or a pressurized system to keep air clean; air conditioning for hot, humid locations.

The market for agriculatural helicopters has been projected to approximately 3,000 new or remanufactured units in the U.S. and a total of 6,000 new or remanufactured units in the free world market by the year 2000. The impact of tightening EPA regulations, focusing on biological controls of insects instead of indiscriminate spraying, together with increasing chemical costs will create a demand for higher productivity, extreme accuracy, and energy efficient methods of pest control. The versitility of the helicopter makes it an ideal vehicle for meeting these challenges.

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1.0 INTRODUCTION

Projections indicate that by the year 2000 the world population will increase from the current 4 billion to 6 billion, a 50 percent increase. Estimates that as many as 450 million people are underfed, mostly in poor countries with rapidly growing populations, underscore the prospects for prosperity in the world agribusiness. The opportunities for an increasing share of the aerial-application market by the helicopter industry are being overlooked by all but a few people in the industry. On the other hand, the ag-airplane manufacturers are aggressively working on increasing the productivity of new ag airplanes by installing turbine engines to reduce weight and drag, increase speed and payload, and cut maintenance costs. NASA Langley is assisting this effort at a nominal annual level of $500,000, while the NASA Ames annual expenditure for helicopter technology is less than 10 percent of the Langley effort.

Approximately $100 billion are spent annually in the U.S. on food production, of which approximately 30 percent is exported. Of the $100-billion agriculture industry, about 1 percent ($1 billion) is spent on aerial application of fertilizers, insecticides, fungicides, herbicides, rodent bait, worm bait, defoliants, seeds, etc. One hundred million dollars worth (10 percent) is applied by helicopters, the remaining $900 million by airplane.

Key questions which this study attempts to answer are listed below:

1. What is the right mix of helicopters and airplanes in agriculture and forestry?

2. Is there a need for a special agricultural aerial-application helicopter? What characteristics would it have?

3. Are turbine powered helicopters and turbine conversions cost effective?

4. How can we increase productivity of helicopters most economically?

5. What is the effect of payload/gross weight on productivity?

6. How can chemical handling hazards be reduced?

7. What are future trends and the impact on helicopters of:

   - Use of granular fertilizers and herbicides in forestry?

   - Use of aerial application for dry fertilizer at high application rates in agriculture?

   - Use of high-rate application of insecticides on orchards and citrus groves?

   - Seeding by air in agriculture and forestry?

   - Biological control of insects?

2.0 HELICOPTER USES IN AGRICULTURE AND FORESTRY

2.1 Background

In 1947 the Civil Aeronautics Board awarded the Bell 47 the first commercial helicopter airworthiness certificate. In the following years the Bell 47 became the first helicopter to be used as a platform for aerial crop dusting.

The first known aerial chemical application in the U.S. occurred at Troy, Ohio, on August 3, 1921 (Reference 1). The pilot, Lt. J. A. McCready, of the Government's Aviation Experimental Station at McCook Field, Dayton, Ohio, and some engineers built a container that could release the chemicals at a constant flow rate, and attached it to the wing of a curtis JN-6 biplane. The experiment was tried on a 6-acre grove of catalpa trees infested with caterpillars. The operation was conducted by flying upwind of the trees and releasing the chemicals from 20 to 35 feet altitude at 80 mph. The wind carried the dust over the entire grove killing the majority (99 percent) of the caterpillars. Six passes were made releasing 175 pounds of chemicals.

At present there are 24,553 agricultural aircraft in the world treating over 575 million acres annually (Reference 2). The U.S. has 8,649 agricultural aircraft treating 180 million acres annually. This 180 million acres is 65 percent of the total number of acres treated in the U.S. each year. There are 808 ag helicopters in the U.S. (9.35 percent of the total number of ag aircraft), and they treat about 18 million acres annually (10 percent of the aerial application). Helicopter flight hours and percentage of total are shown in Table I.

TABLE I

FLIGHT HOURS FOR AERIAL APPLICATION IN U.S.

	Total	Helicopter	Helicopter % of Total
1968	1,282,000	74,362	5.8
1969	1,328,000	83,200	6.25
1970	1,520,000	101,192	6.7
1971	1,407,000	97,047	6.9
1972	1,773,000	140,072	7.9
1973	2,020,400	139,470	6.9
1974	2,085,400	149,366	7.2
1975	2,172,900	148,660	6.8
1976	2,498,500	161,437	6.5
1977	2,059,556	201,385	9.8

Data Source: NTSB/FAA Records

Many different types of helicopters are being used in aerial application. (Ref. Table II). Russia and Japan have done extensive studies in the use of helicopters in aerial treatment of crops.

TABLE II

HELICOPTERS IN AGRICULTURE

(Including row crops, brush control, forestry, and firefighting)

Manufacturer/Type	United States			Canada		
	Coml	Corp/ Private	Govt	Coml	Corp/ Private	Govt
Aerospatiale						
Alouette II	3	0	0	5	0	0
Alouette III	5	0	0			
Lama	4	0	0	0	0	0
Gazelle	0	2	0			
Bell						
47 (All varieties)	456	23	30	55	4	2
204	0	0	1	5	0	0
205	7	0	2	3	0	0
206	47	22	16	41	4	8
212	0	2	0			
Tomcat (derivative of Bell 47)	57	0	0			
Brantly (all)	10	1	0			
Boeing Vertol 107-II	7	0	0			
Enstrom F-28	4	3	3			
Hiller						
UH-12	75	0	9	5	0	0
UH-12-J3	5	0	0			
FH-1100	8	0	0	1	0	0
Hughes						
300 (inc 269A)	50	17	8	2	1	0
500	29	7	0	5	1	0
Kaman H-43A/F	1	0	7			
Sikorsky						
S-55	14	0	0	1	0	0
S-61	4	2	0			
S-64	5	0	0			
Totals	791	79	67	123	10	10

Source: Helicopter Association of America, except for new data from Tomcat manufacturer which raises the total U.S. ag-helicopters to 937 (1976).

2.2 Russian Agricultural Helicopters

According to a NASA-translated Russian agricultural report (Reference 3), the USSR first used helicopters for agriculture in 1958. In 1974, the Russians reported spraying 226 million acres (90,400,000 hectares). On a trip to Russia in September 1978, Dr. Bruce Holmes of NASA Langley was told that approximately 15 percent of the Russian application is by helicopter.

The Russians believe that their helicopters produce a better quality of pesticide distribution over the surfaces being treated. They believe that the powerful downwash of the helicopter helps to mix the chemicals and send them groundward at steep angles intensely enveloping the plant growth and covering both upper and lower sides of the leaves at all levels.

The USSR claims that the cost of operating their Mi-2 and KA-26 helicopters is only slightly higher than the cost of operating their fixed-wing Agriculture Plane, the AN-2. They also claim that the helicopters cost somewhat less to operate than ground equipment.

2.3 Japanese Agricultural Helicopters

A report by the Agricultural Relations Committee in Asia (Reference 4) stated that Japan introduced the helicopter for forestry use in 1954. Ten years later (1964) Japan went exclusively to the use of helicopters for agriculture and forestry spray operations. In 1975, Japan treated 77,299,640 acres (3,091,982 hectares), all by helicopter.

Japan has very small agricultural fields, placed close together, and often surrounded by population or other food sources, such as fisheries. To avoid poisoning the population and wildlife, toxic spray drift must be kept to a minimum. The cost of operating helicopters is of small importance compared to the possibility of damaging expensive food products. Japan must continue to produce high-yield harvests to feed its relatively large, dense population.

2.4 U.S. Agricultural Helicopters

The agricultural spraying market has been increasing annually at a rate of about 12 percent per year (Reference 2). The helicopter's share of this market is also increasing annually. As the market continues to expand, more uses will appear where the helicopter is more economical than the airplane. Certain guidelines become apparent when an operator decides whether to use an airplane or a helicopter.

1. Field size - Helicopters can spray small fields (10 to 100 acres) more effectively than airplanes and much quicker than ground equipment.

2. Ferry time - Helicopters land, refuel, and reload from nurse trucks at the field and therefore can operate at greater distances from fixed bases. In confined areas they can even land on the nurse trucks (Figure 1).

Figure 1. Operating from the Top of a Nurse Truck

3. Obstacles - Because helicopters operate at slower airspeeds and are more maneuverable, they can operate in and around obstacles and congested areas (i.e. buildings, towers, powerlines, etc.)

4. Customer desire - In many cases customers prefer using a helicopter. Many believe that the helicopter gets better pentetration and more even coverage. The farmer can talk to the pilot and ground crew and oversee mixing and loading procedures beside his field. He can also fly over the field with the pilot to point out specifics of the spraying operation.

Reference 5 is a thorough review of the state-of-the-art in aerial-application systems. It contains detailed discussions of dispersal system and ground support equipment, and makes recommendations for future research.

2.5 Insecticides and Other Chemicals

Of all the chemicals applied aerially in the United States, 52 percent are insecticides (Reference 2). These chemicals are applied to most crops at a rate of 1 to 5 gallons per acre. Even coverage and minimal drift is the key to applying insecticides. Even coverage is important in that any heavy concentrations can leave "burn marks" on the crop which would destroy its appearance and be detrimental to growth. There are many different types of insecticides, designed for various species of insects and crops. If an insecticide is applied to a crop other than the one it is designed for, the results could be devastating. Therefore drift must be watched carefully to ensure that neighboring crops are not destroyed. For these reasons helicopters are very well suited to the insecticide-application market.

Following insecticides, the most used aerially applied chemicals are herbicides, fertilizers, fungicides, seeds, and defoliants. Some other operations include spreading rat pellets, worm bait, and bird inhibitors.

2.6 Effects of Chemicals on Crops

Most chemicals applied from the air are designed to be used in specific concentrations and quantities. Figure 2A shows what a plant should look like when the spraying is done properly. The droplet size is very small and the droplets are evenly distributed across the leaves. Figure 2B depicts a plant that was improperly sprayed. There are blotches of chemicals on the leaves; this could cause burn marks and leave parts of the plant unprotected. Blotching is usually caused by too large a droplet size. Occasionally it is caused by bad chemicals, to heavy a concentration, or improper mixing.

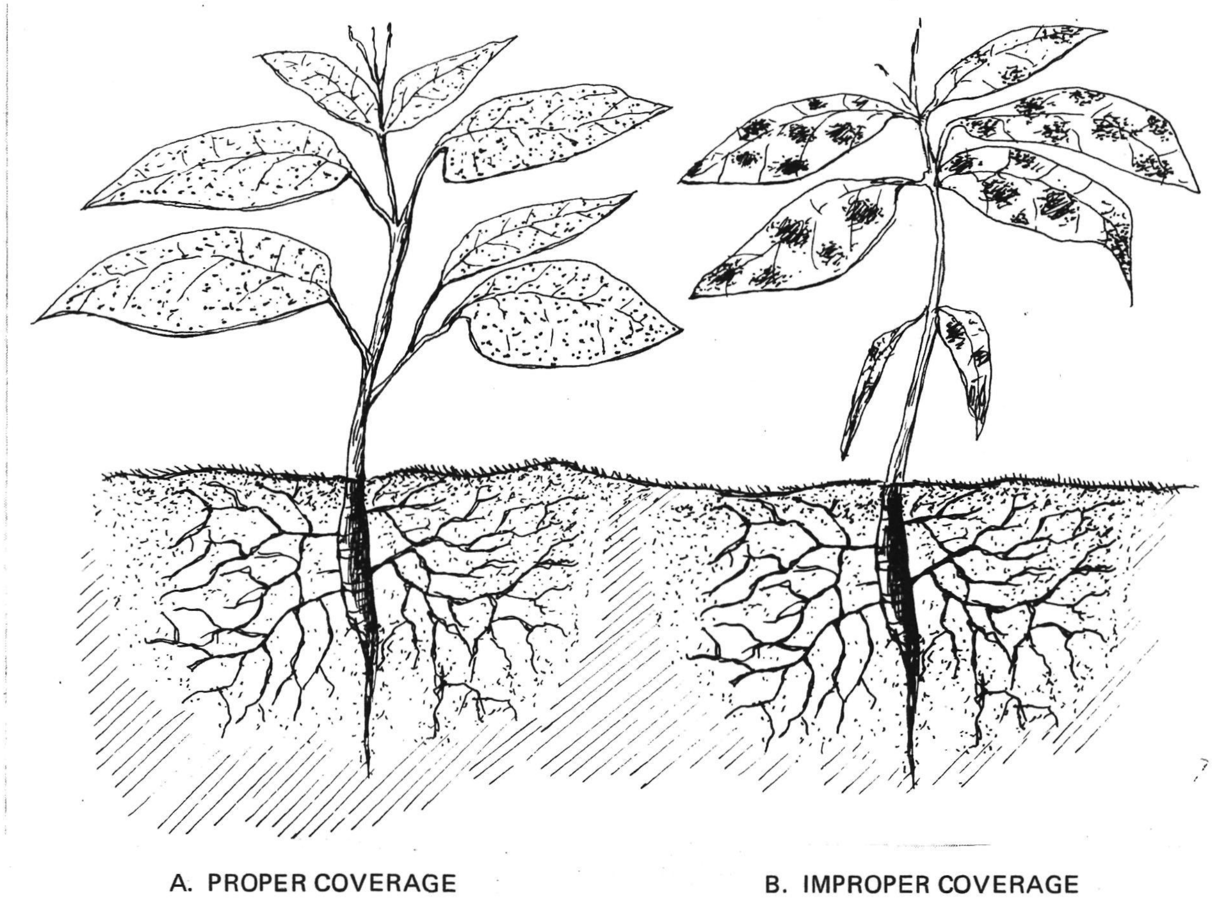


Figure 2. Examples of Ways Chemicals Affect Plants

2.7 Seeding

Seeding rice is a complex operation because of the nature of its fertilization process. Rice seeds will only germinate in close proximity to other rice seeds; therefore, if a handful of rice is thrown on moist ground, it will only sprout in areas were seeds are clumped together. This results in scattered patches of sprouts that will suffocate each other as they grow. In Asia these clumps are normally dug out and the sprouts replanted, one at a time, by hand. When seeding rice by aerial application, the rice is germinated and then suspended in a liquid emulsion (detergent). This emulsion keeps the seeds separated after they are dropped onto the surface of the field, which is flooded. Although this process is still relatively expensive, it is the only practical method for seeding rice in the U.S. where labor costs are high.

Wheat is seeded at a rate of 180 pounds per acre. Most of the helicopters being used in agricultural spraying do not have the payload capability to seed wheat efficiently.

Alfalfa is more adaptable to seeding by small helicopters because it is a much lighter seed - it is seeded at a rate of 10 pounds per acre. Alfalfa seeding is often done by helicopters for about the same price as a 3-gallon-per-acre application of liquid chemicals.

Various grasses, clovers, and tree seeds are spread by helicopter. Many require special techniques such as mixing a wet slurry of seed and fertilizer to provide even seeding and simultaneous fertilizing (Figure 3).

Figure 3. Aerospatiale Lama Dispensing a Wet Slurry of Seeds and Fertilizer

2.8 Agricultural Helicopter Pilots and the "Turnaround"

The agricultural helicopter pilot is highly skilled in low speed low level flying. Interviews with pilots of agricultural helicopters resulted in the following description of "field end turns".

During a swath run the pilot's attention is on holding a straight course so as not to overlap (burn) an area or stray away from the last swath (skip an area). As he nears the end of his run he concentrates on the obstacles ahead deciding when to turn off his spray and begin his turnaround. The helicopter is still at spray speed as the turning point is reached. The pilot simultaneously turns off the spray and executes an abrupt cyclic climb while lowering the collective to reduce speed. The helicopter loses speed in the quick climb, and the pilot steps on the left or right antitorque peddle, turning into the wind. Nearly motionless in the air, the helicopter reverses direction in a 180° torque turn. Now the helicopter is heading groundward at a high rate of descent as the pilot trades altitude for airspeed.

The pilot levels the helicopter with cyclic, bringing in power and collective, maintaining rotor rpm. He turns on the spray, beginning his return swath accurately next to the preceding one. This entire procedure occurs in about 8 seconds for the Hughes-300-size helicopter at a 45-mph swath speed. The time varies with swath speed, gross weight, and power margin .

The ability of a helicopter pilot to execute this field-end turn while turning his spray off and on again and maintaining a proper swath width distinguishes him as an agricultural pilot, and places him in a category of superior ability to other helicopter pilots.

Average turn time for the smaller ag-airplanes is approximately 30 seconds because of higher swath speeds (100 to 110 mph) and less maneuverability at low speeds than helicopters (Figure 4 and Reference 6). Turn time for ag helicopters is much less of a consideration than for ag airplanes.

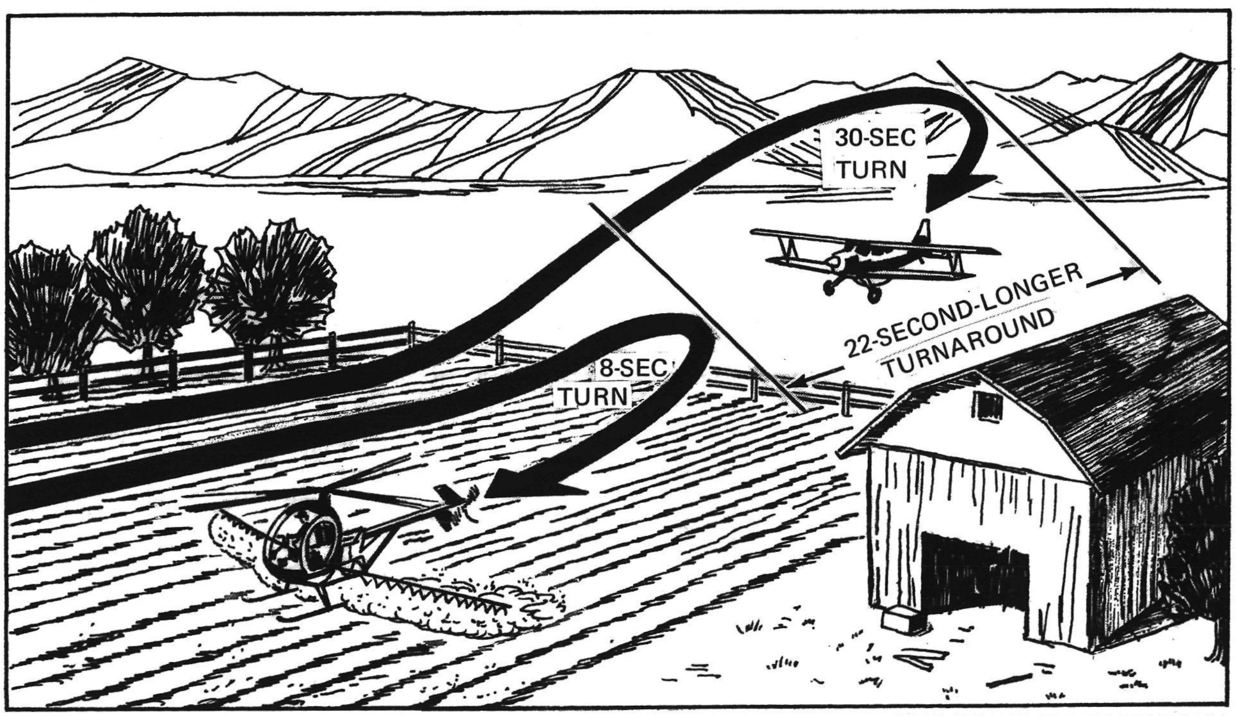


Figure 4. Turnaround Time Comparisons Between Helicopters and Airplanes

2.9 Dry Chemical Application

Slinger buckets are used for spreading various types of dry chemicals, such as, crushed corn that has been treated with bird inhibitors, rat pellets, seeds, fertilizer, and worm bait. The most common bucket uses a small gasoline engine to turn a rotary slinging device on the bottom of the bucket. Most buckets are suspended on a sling (Figure 5), but some dry slingers are attached directly to the helicopter and have side-mounted loading tanks (Figure 6).

Figure 5. Hughes 500D with Sling-Type Dry Spreader

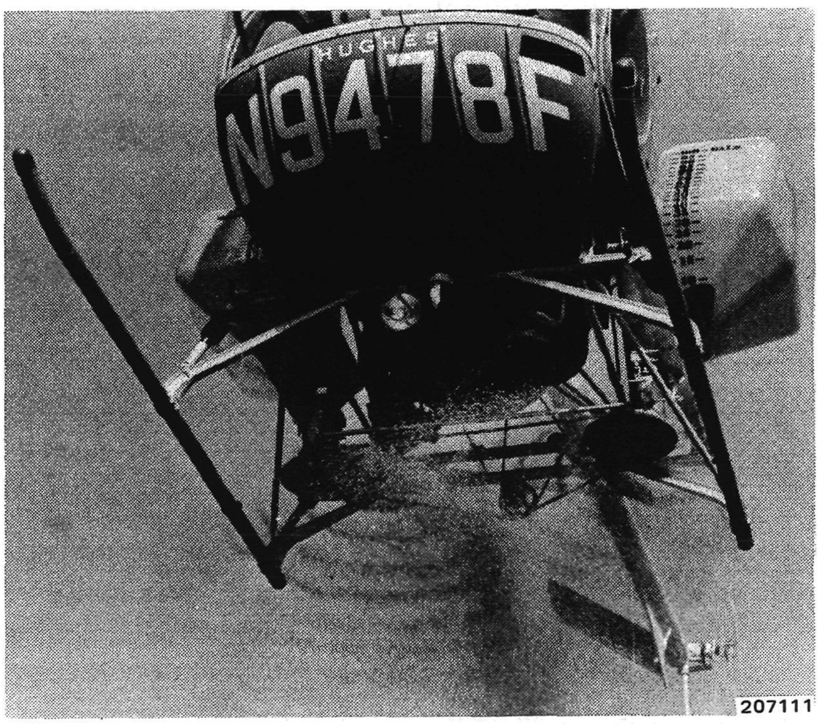
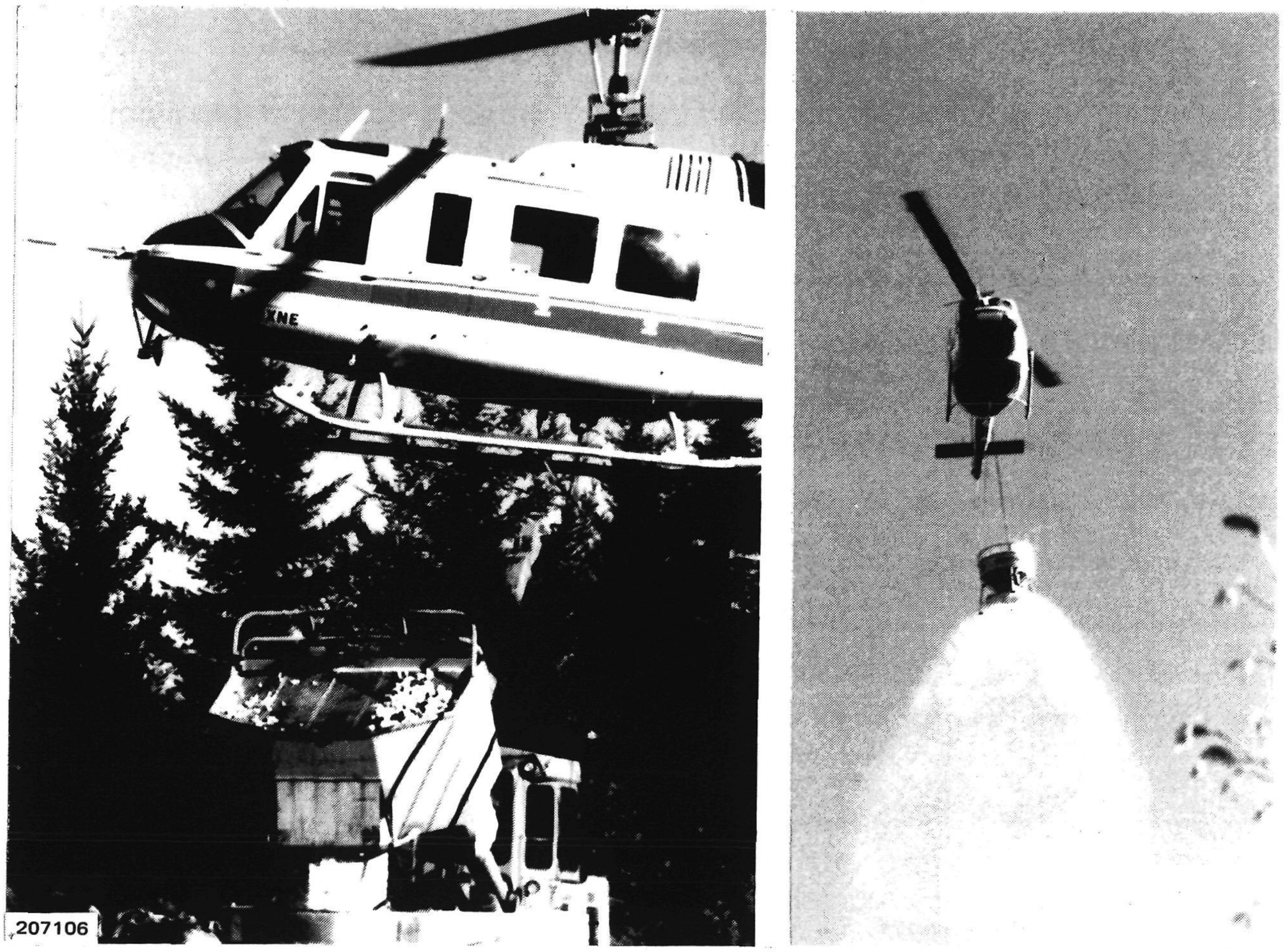


Figure 6. Hughes 300C with Airframe-Mounted Dry Spreader

Most rotary slingers are operated by hydraulic or electrical power-takeoff motors, or by gasoline engines. Other slinger designs use pneumatic pressure to blow the materials outward.

Forest fertilizing is done by making two or three passes over the same area to achieve the required uniformity and rate (440 pounds per acre). Bell 205 helicopters are currently used in Canadian forests (Figure 7). They use external buckets which have a capacity of 3,500 pounds. They fly at 65 mph and cover a swath 200 feet wide. To achieve the required rate, the effective swath is 65 feet. The technique is for the pilot to index over 65 feet for each successive pass, which means that he covers the same 65-foot swath three times with his 200-feet-wide spray. Similar tests were conducted in U.S. forests using a Boeing Vertol 107-II helicopter (Figure 8). They used either an external bucket with a capacity of 8,500 pounds or an internal load of 6,500 pounds. The pilot flew at a speed of 70 mph about 50 feet above the forest canopy and covered a swath 200 feet wide. However, the larger helicopter achieved an effective swath of 100 feet. So it could index 100 feet with each pass and still spread the fertilizer at the required rate and uniformity.



Bucket Loading

Spreading Fertilizer

Figure 7. Bell 205A with Fertilizer Bucket

COLUMBIA HELICOPTERS, INC.

Figure 8. Boeing Vertol 107-II Dispensing Fertilizer From Internal Hopper

Limitations in swath width are with the slinger equipment, which tends to break up the granules if more slinger rotational speed is applied. The other problem is the speed in loading internally. For details see Appendix C.

2.10 Agricultural and Forestry Application Productivity

Helicopter application efficiency is mainly a problem of using the rotor downwash and tip vortices to distribute the chemicals evenly in the widest possible swath at the highest practical speed (Figure 9). Operator experience varies greatly over a wide range of crops and operating conditions. Some operators feel that the Bell 47 is the right size helicopter if it could carry 120 gallons with a reasonable power margin. Others have been unable to use the 47 on orchard and citrus crops because of a need for more downwash to force the spray into the trees and provide even distribution and coverage. This is particularly true at high application rates (20 to 40 gallons per acre) as used for some tree crops. In addition, for moderate and high application rates on large acreages, there is a need for larger helicopters for both liquid and dry materials. In forestry there is an increasing market for high application rates of dry fertilizers. In this case limited access of ground equipment and mountainous terrain make more powerful twin-engine helicopters attractive. Twin engines are much safer in forestry work.

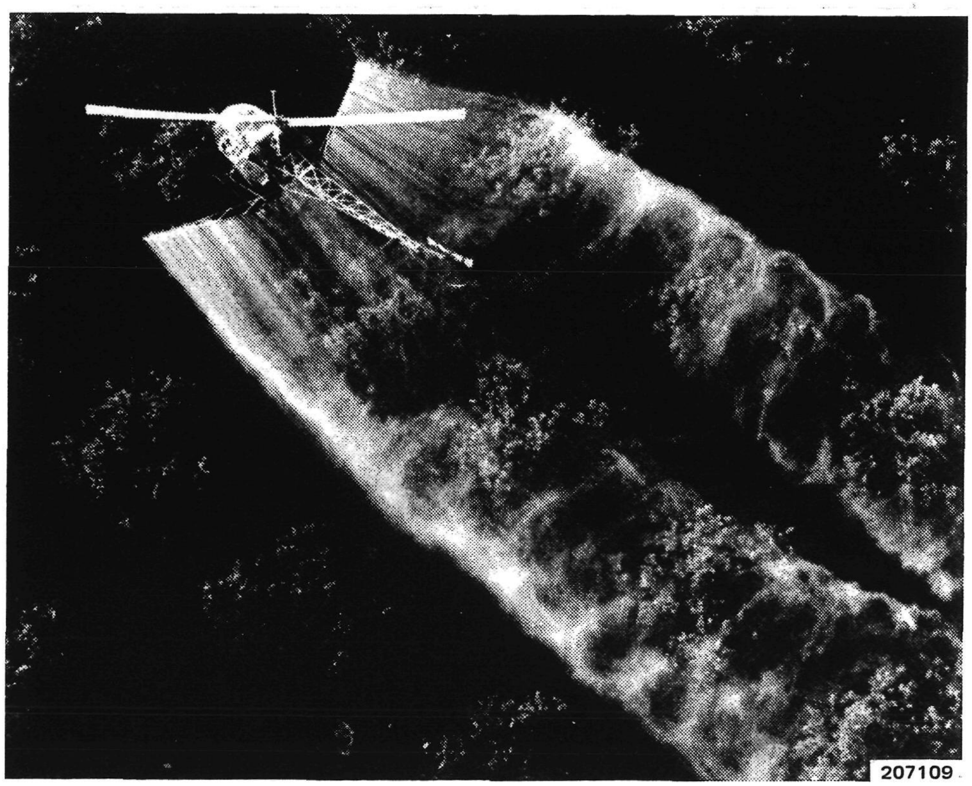


Figure 9. Effects of Rotor Downwash and Tip Vortices on Spray Distribution

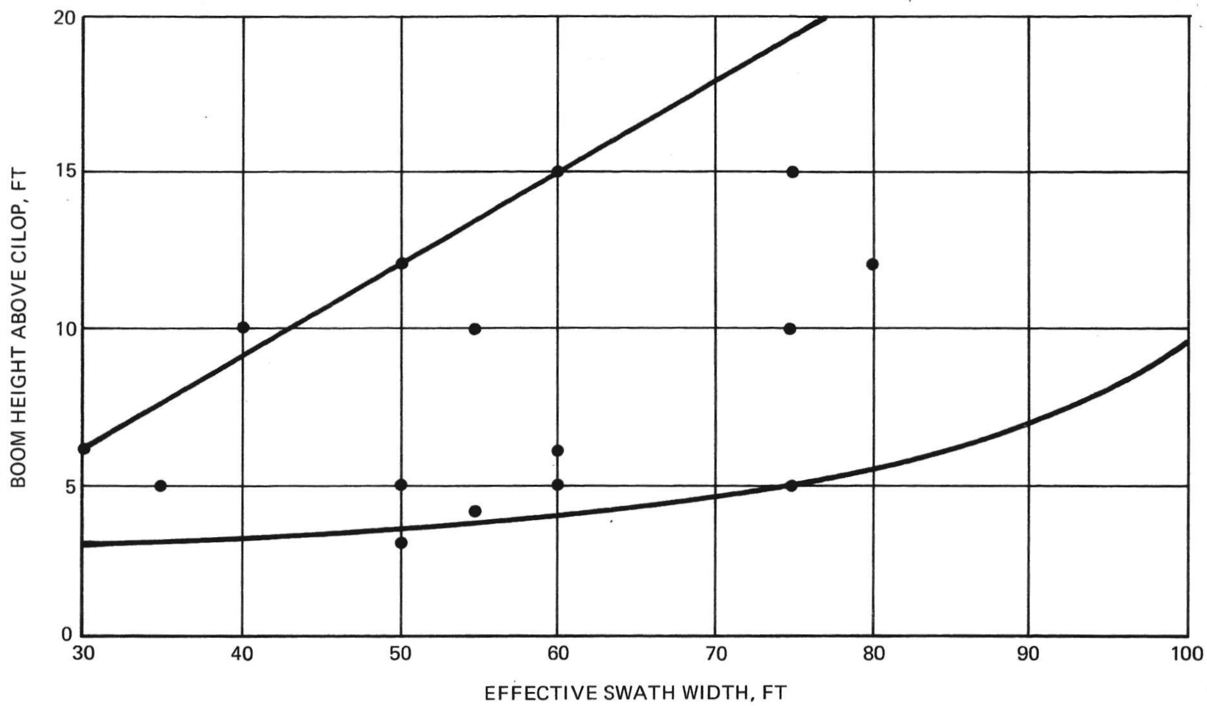


Figure 10. Relationship of Swath Width to Height of Boom Above the Crop

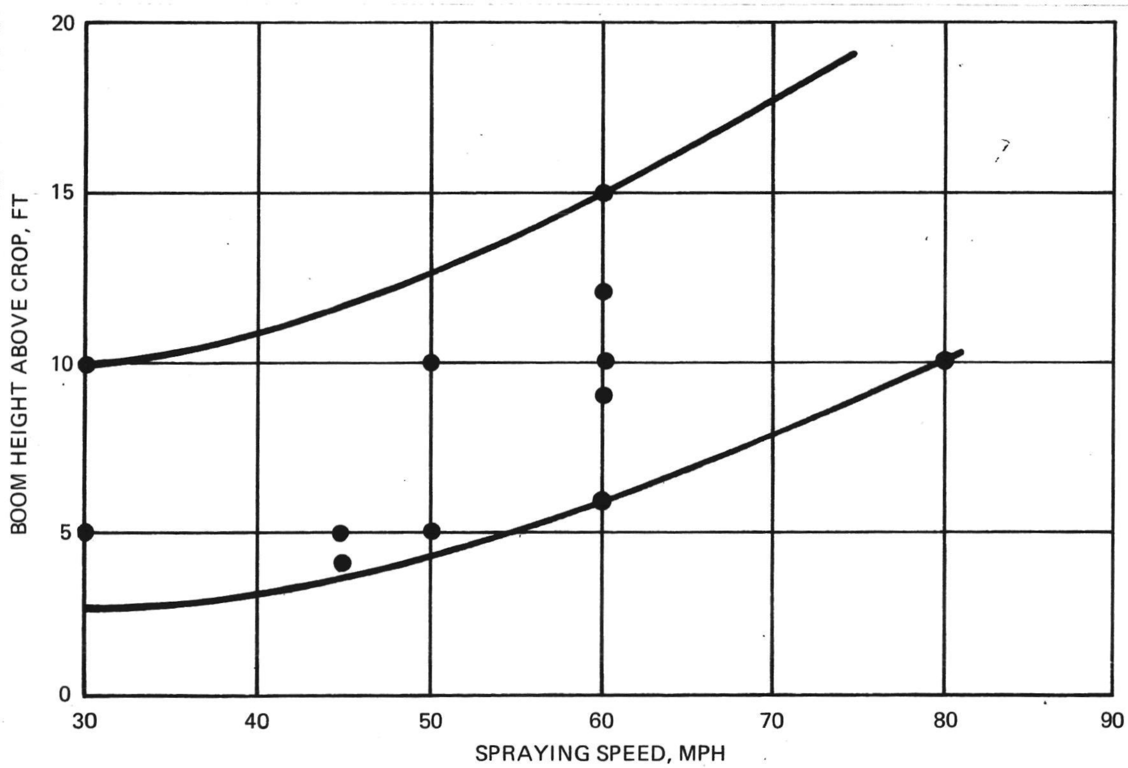


Figure 11. Relationship of Spray Boom Height to Spraying Speed

2.11 Swath Width

Figure 10 shows a scatterband of swath width versus height above the crop. This relationship varies widely because it depends on the crop, flatness of the field, speeds flown, type of helicopter, and spray-boom configuration. Extremes such as 30 mph at 10 feet above the canopy for orchards and 80 mph at 10 feet above the crop for wheat are shown in the scatterband in Figure 11, which illustrates the speed/height relationship. Since pass speed and swath width are the two most powerful parameters in determining productivity of helicopters, it is important to understand how to increase speed and swath width and maintain good coverage. At present most operators do their own flight test program to determine pass speeds and estimate the effective swath width. Many also experiment with nozzles and chemical additives to influence droplet size and dispersion. When an effective combination is arrived at by this method, the operator will stick with the technique. The more successful and lower priced operators are constantly experimenting with flight techniques and different equipment, for both liquid and dry materials, to improve the operation.

An example of the importance of tailoring the operation to local conditions and needs is the growing use of larger, higher payload helicopters such as the Sikorsky S-55. Payloads range from 150 gallons to 225 gallons depending on temperature and altitude conditions. This is approximately twice the payload of the Bell 47 series and Hiller 12E's and 1.5 times the Bell 206 and Hughes 500. The S-55 has the following advantages:

- Orchards - The stronger downwash pushes the chemical mixture down into the foliage and gives a 60-foot-wide swath at 30 mph. The work can be done at less cost per acre and with better coverage than with ground spraying equipment. Since the application rate is up to 40 gallons per acre, high payloads are needed to prevent excessive time lost in loading and ferrying. Frost control in orchards is also much more effective with the more powerful downwash of the heavier aircraft.

- Corn and Soybeans - The higher payloads permit spraying larger acreages and less frequent reloading. Longer ferry distances can be accommodated than with smaller aircraft because more acreage can be sprayed in one trip. Also, small fields enroute can be sprayed while the nurse truck is relocating, which saves time if long distances are involved. Swath widths of 75 feet for herbicides and 100 feet for insecticides at 45 mph and 60 mph respectively are achieved at rates of 1 to 5 gallons per acre.

The swath width is limited by the length of the spray boom, the height flown above the crop, and by rotor downwash power. Swath width can be increased by flying higher over the crop but this induces a drift problem and loss of penetration control. Many agricultural helicopters will fly 3 to 5 feet off the crops being sprayed on flat fields. Another way to increase swath width is to increase the boom length. Boom length is usually limited to 5 to 15 feet more than the rotor diameter on small helicopters. Also, longer booms increase drag and thus limit attainable airspeeds. The ideal airspeed for agricultural helicopter work is around 100 mph. Most of today's agricultural helicopters are spraying at maximum speeds of 60 to 80 mph because they are limited by power, structural loads, or nose-down attitude. Probably the most effective way to increase swath width is through a combination of maximum practical boom width and more powerful downwash with larger helicopters. For small helicopters in the Bell 47 class, 50-foot swath widths at 50 mph are a practical limit. Larger helicopters, of the S-55 class, can achieve 75- to 100-foot swath widths at 60 mph with spray booms slightly shorter than the rotor diameter. Speeds of 80 mph, and up to 75-foot swath widths are being accomplished with the Bell 206 (Figure 12). The swath-width-versus-speed scatterband is shown in Figure 13.

OMNI FLIGHT HELICOPTERS

Figure 12. Bell 206 with Spray Rig

For application of insecticides over large areas of forest, airplanes such as the DC-6 are being used in Canada and the eastern U.S. In the western U.S., forests are usually treated by helicopter because of mountainous terrain, a desire for accuracy and maximum effectiveness, and because there are smaller forests. Controlled tests by the U.S. Forest Service with a Boeing Vertol 107 helicopter are reported in Reference 7 (see Figure 14). The spray-boom length was 97 feet, rotor diameter 50 feet, spraying speed 90 mph, and spray height 70 feet. The average swath width achieved was 254 feet on 11 flights. The report concluded that the Boeing Vertol helicopter with the prototype spray system was a satisfactory tool for aerial application of pesticides. It recommended that "this aircraft should be further tested to establish the effect of rotor wake, vortices, and downwash on dispersal of spray under open ground and forest conditions".

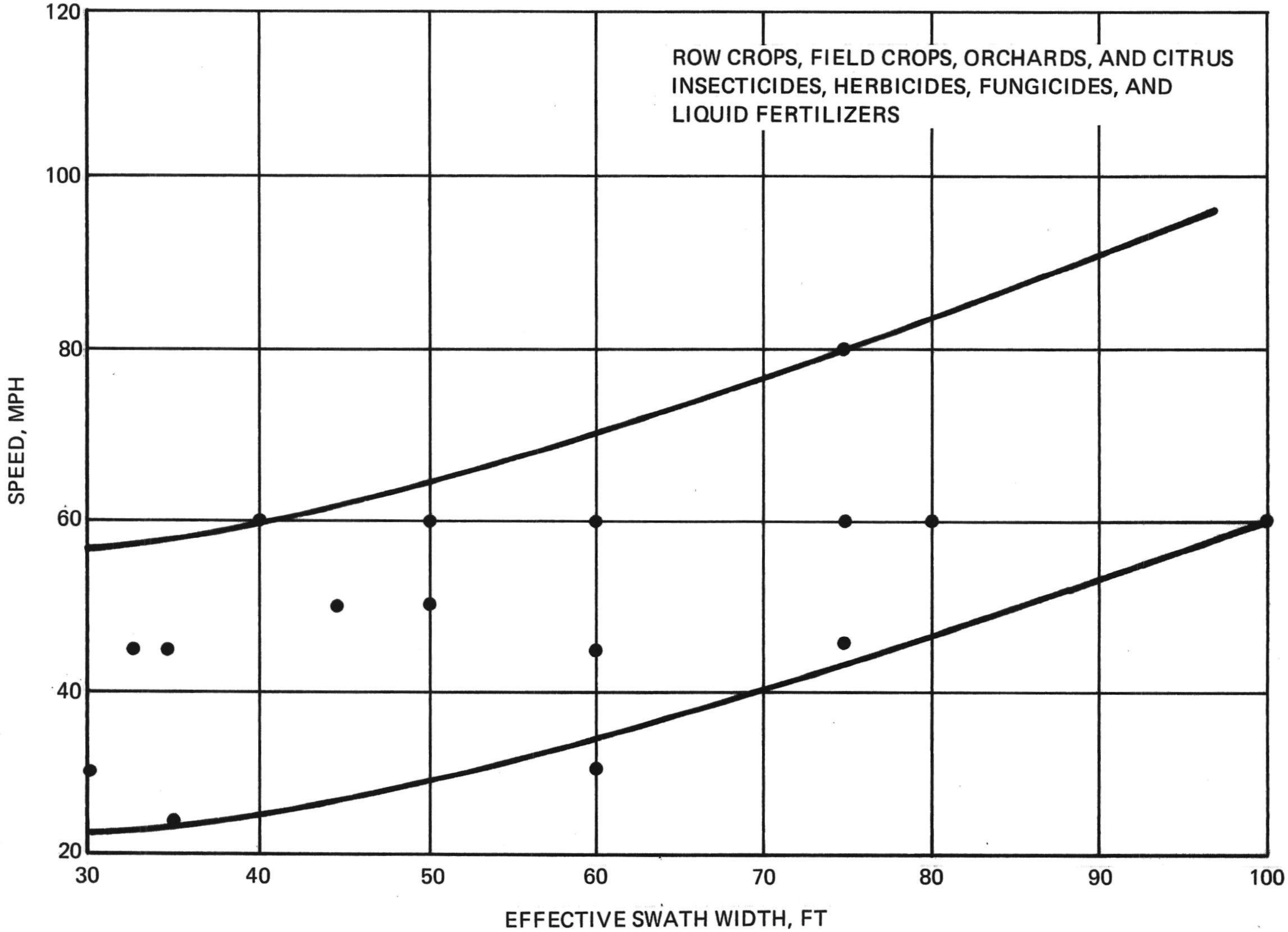


Figure 13. Relationship of Swath Width to Speed

Figure 14. Boeing Vertol 107-II with Spray Rig

Reference 8 reports a 1973 evaluation of a Bell 205A-1 helicopter equipped to spray insecticide on forests. On a large forest spray program the Bell 205A-1 helicopter sprayed an average of 877 acres per flight hour at an application rate of 1 gallon per acre for a cost of \$1.78 per acre. The spraying speed was 90 mph and swath width was 200 feet, with an average load of 250 gallons. Ferrying speed was 120 mph. Correcting the cost from 1973 to 1978 in accordance with DOD rate adjustments results in \$1.78/acre x 1.785 = \$3.18/acre. These results demonstrate that for large scale spraying of insecticides the helicopter productivity of 877 acres per flight hour is cost effective but can only be achieved with large aircraft with high payloads, high speeds, and wide swaths. Figure 15 shows a Bell 205 spraying forests in a configuration used by another operator.

Swath widths for application of dry materials is discussed in Section 2.9.

2.12 Off-Season and Supplemental Revenue

Many northern agricultural helicopter operators have the opportunity to do off-season work with their helicopters. It is not uncommon for an operator to do agricultural spraying for 6 months and then do charter, flight training, and other short-term jobs in the fall and winter seasons. Some of the off-season and supplemental jobs are listed below.

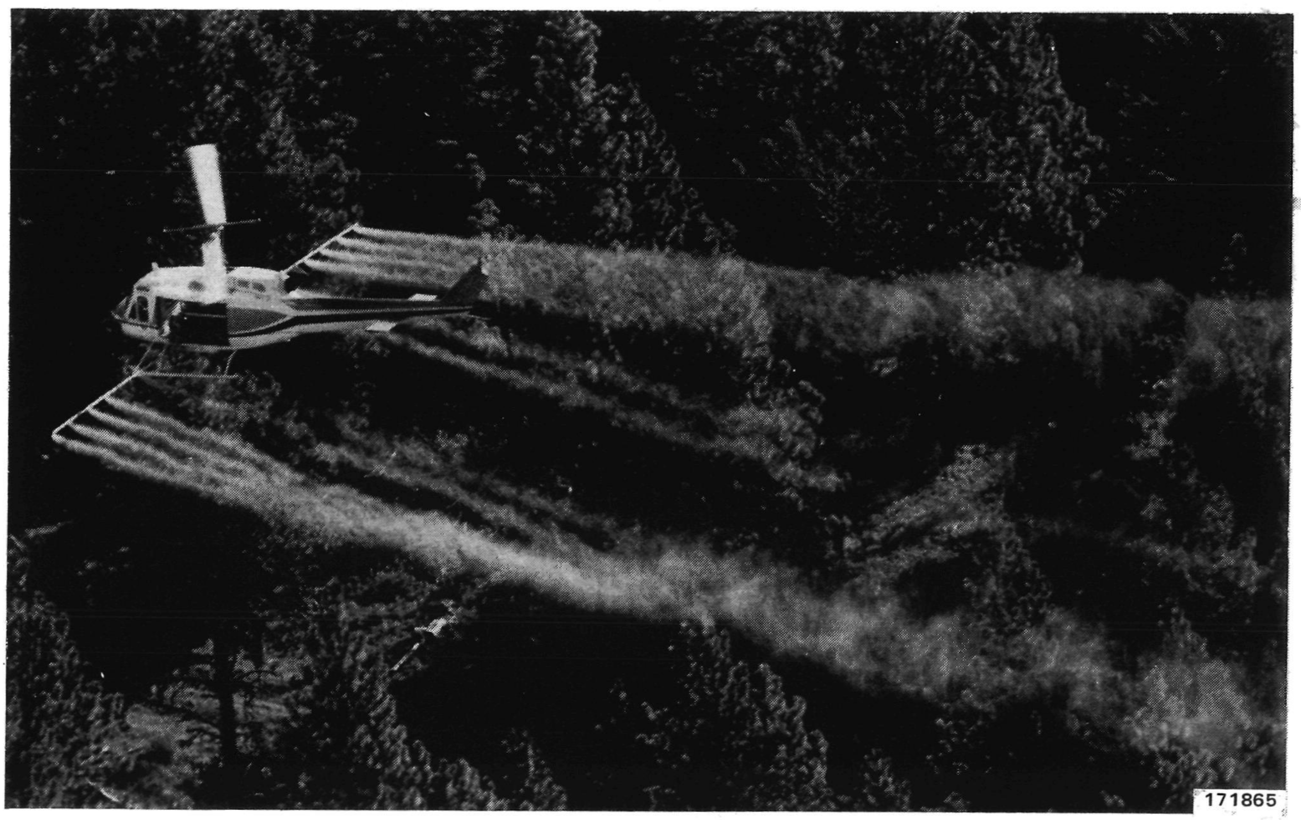


Figure 15. Bell 205A Spraying Forest

- Pollinating corn
- Support of logging operations
- Frost protection
- Mosquito abatement
- Wire and pipeline patrol
- Wildlife surveys
- Aerial photography
- Livestock herding
- Winter salt and feed drops
- Construction
- Emergency fruit drying
- Tourist rides
- Aerial ambulance
- Dormant spraying
- Winter fertilizing
- Rustler patrol
- Flight training
- Seeding
- Fire patrol and firefighting
- Wildlife counting
- Wildlife predator control

2.13 Useful Load, HOGE Altitude, and Acquisition Cost Comparisons

Table III is a listing of typical helicopters used in agriculture and forestry. The most critical relationship to the operator is useful load, Hover Out of Ground Effect (HOGE) altitude, and acquisition cost. For this table the average retail cost for a low-time latest model was used from The Helicopter Blue Book (Reference 9). The table shows a wide variation in HOGE altitudes for standard day temperatures. In general, the power match with the older reciprocating-engine helicopters is poor, and therefore even at low density altitudes useful load must be reduced.

The turbine helicopters were designed with higher installed power having lower weight per horsepower which results in a much better power match and useful load capability at high altitudes and high temperatures.

Turbine conversions offer a striking example of good power match; useful load is actually increased and can be carried to much higher altitudes. This is possible because the turbine engines have more power than the reciprocating engines that they replace, and yet they are substantially lighter. For example, a typical turbine conversion empty weight is 272 pounds lighter and has 140 horsepower more takeoff power. The net effect is to increase payload by 272 pounds and also improve high hot performance.

The higher acquisition costs of turbine helicopters can be justified on the basis of versatility, higher utilization, and higher payloads throughout the altitude/temperature envelope.

2.14 Turbine Power Considerations

The higher power available with the turbine engine combined with its lighter weight results in a better useful-load to gross-weight ratio compared to reciprocating engines throughout the altitude envelope and at high temperatures at low altitudes. Additional benefits of turbine power are higher reliability and lower maintenance costs than reciprocating engines.

TABLE III

SELECTED HELICOPTER COMPARISONS
Useful Load, HOGE, Altitude, and Acquisition Cost

Helicopter	Gross Weight, lb	Useful Load, lb	HOGE Alt, Std Day, ft	Acquisition Cost [1] $/1,000
300C	2,050	1,000	8,600	55.5
UH-12E	2,800	1,034	7,200	61
47G-5A	2,850	1,143	1,400	62
Soloy 12E (T)	2,800	1,150	12,000	120
Soloy 47 (T)	2,950	1,380	20,000	140 [3]
206B	3,200	1,604	5,800	192
500D	3,000	1,640	7,500	210
S-55	7,500	2,250	2,300	80
205A-1	9,500	4,298	6,000	750
212 (Twin)	11,200	5,242	5,200 [2]	990
S-61N/L (Twin)	19,000	6,744	3,800	3,500
107-II (Twin)	19,000	8,800	8,000	NA [4]

1. Based on average low-time late-model base retail price. Source: The Helicopter Blue Book, 1979
2. At 10,500-lb gross weight
3. From Soloy
4. Infrequently traded

Rotor & Wing

3.0 SAFETY HAZARDS AND POTENTIAL SOLUTIONS

3.1 Safety Data on Aerial Application Aircraft

National Transportation and Safety Board (NTSB) accident data for the years 1968 through 1977 were analyzed to determine accident rate trends for helicopters and airplanes used in aerial application roles. Figure 16 shows a steadily reducing trend in accidents, per 100,000 flying hours, but the helicopter rate is more than twice the ag-airplane rate. This is probably because the helicopter is employed in the more hazardous operations - in smaller fields with many trees, poles, and wire obstacles and in orchard and forest work where engine failures are more dangerous. Another factor which may influence these rates is that some percentage of the flight hours go unreported, but all accidents involving significant structural damage are reported. Therefore the accident rates may be somewhat inflated. The degree of unreported flight hours are probably about the same for helicopters and fixed-wing aircraft, so the relative accident rates are believed to be realistic.

Note: The Helicopter Association of America (HAA) has recently challenged the FAA breakout of flight hours for helicopters in aerial application work. Although the numbers given in Reference 10 may not be exact, they are the best available in published data, and they present a relative comparison of the helicopter and airplane used in aerial applications.

The fixed-wing aerial-application accident rates are about the same as helicopter accident rates in general. This reinforces the conclusions made in previous reports that helicopter safety improvements should be high on the list of critically needed research if the industry is to achieve its full growth potential.

Figure 17 shows that the rates of accidents which result in the aircraft being written off follow the general trend for basic accidents.

Figure 18 illustrates that the fatal accident rates are about the same, on the average, for helicopters and airplanes in aerial-application roles. Figure 19 shows the actual number of fatalities by year. A conclusion can be drawn from this - since the helicopter has more than twice as many accidents as the airplane but the fatality rates are about the same, the helicopter is more survivable. Figure 20 shows that this also holds true for helicopter and airplane crashes in non-aerial-application roles.

Figure 21 shows flight hours recorded by NTSB and illustrates that helicopters flew approximately 7 percent of the recorded aerial-application flight hours except for 1977 which increased to 10 percent. NTSB personnel believe that the flight hours for 1974, '75, and '76 may be higher than shown by about 7 percent and are trying to clarify flight hours for these years. 1977 is believed to be accurate.

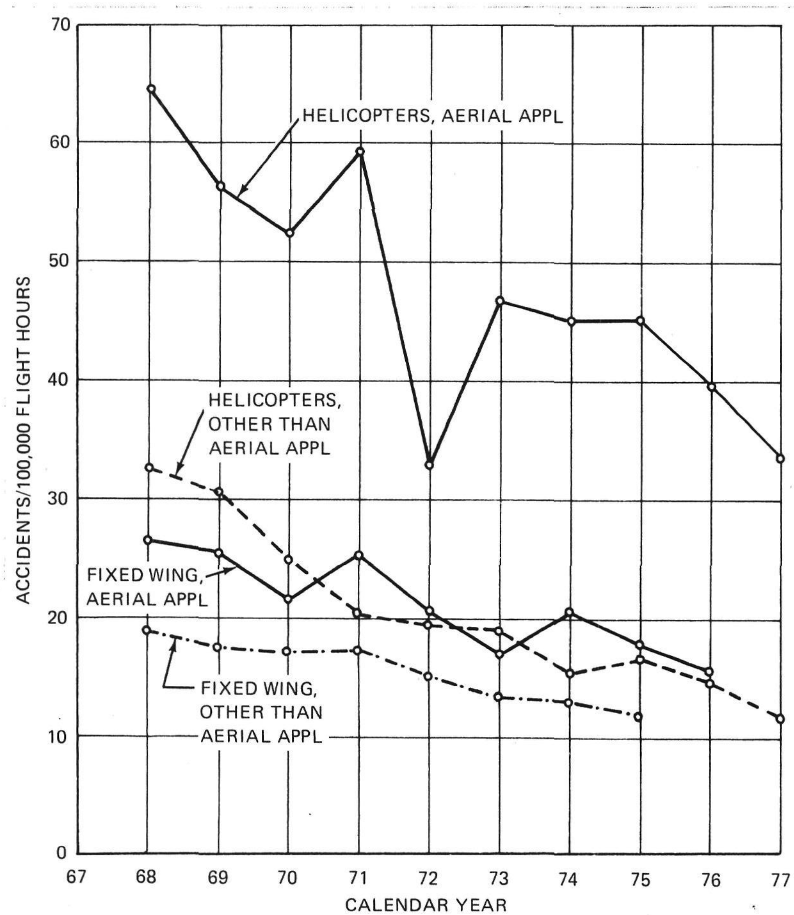


Figure 16. Accident Rates per 100,000 Flight Hours

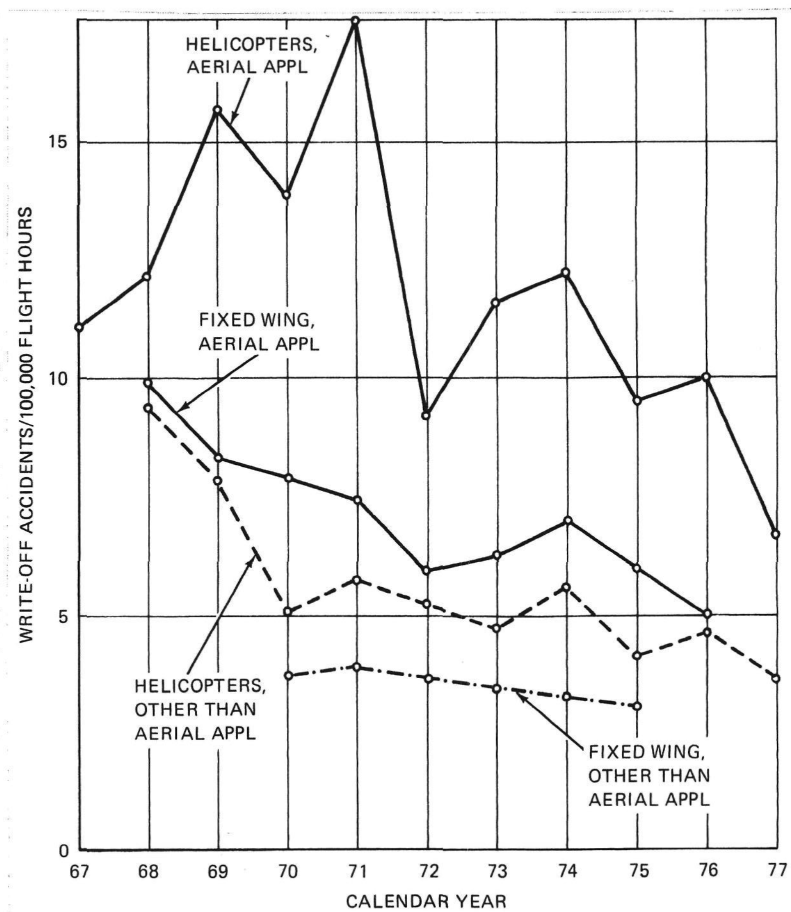


Figure 17. Write-off Accident Rates per 100,000 Flight Hours

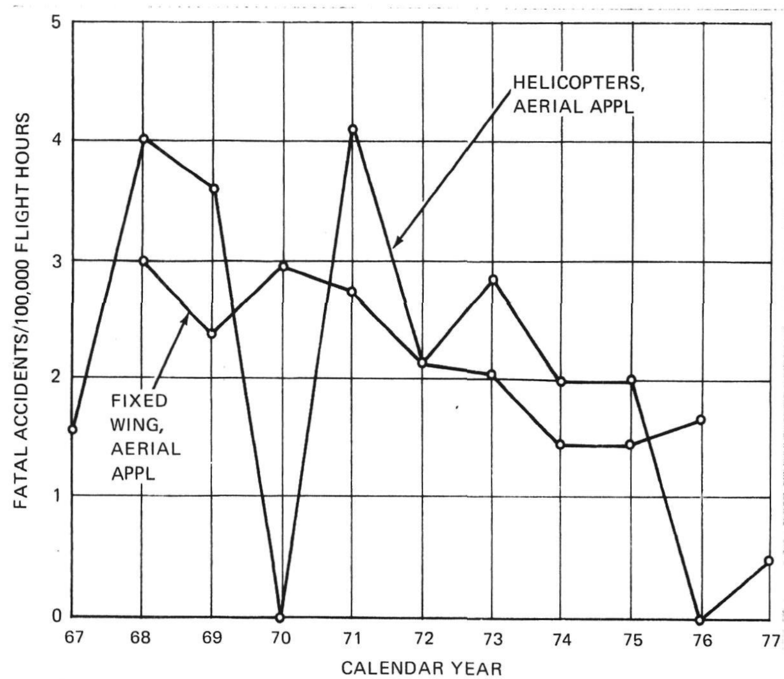


Figure 18. Fatal Accident Rates per 100,000 Flight Hours

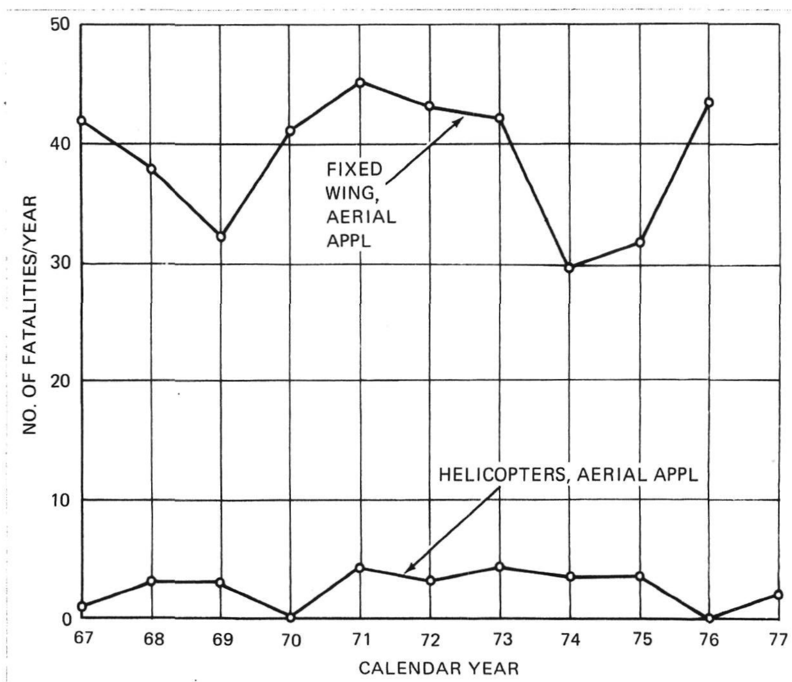


Figure 19. Number of Fatalities

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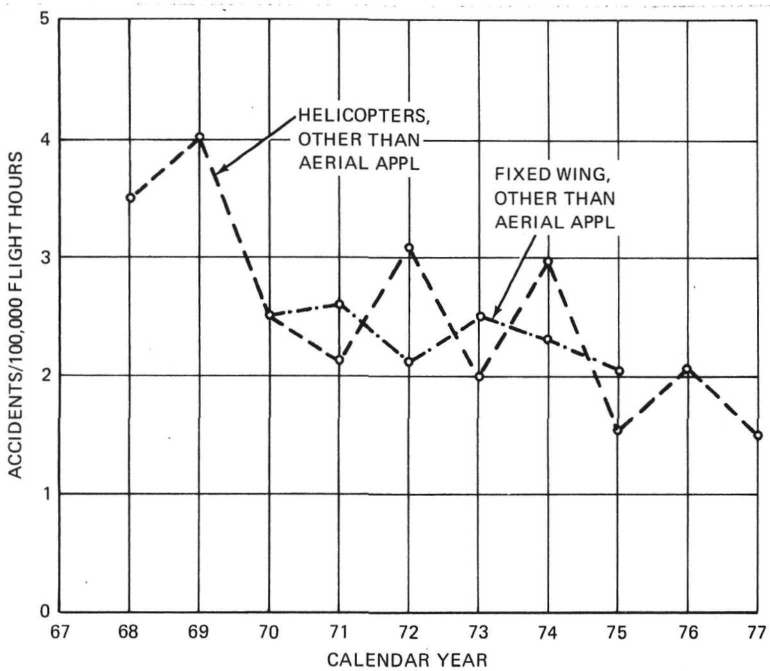


Figure 20. Fatal Accident Rates per 100,000 Flight Hours, Other than Aerial Applications

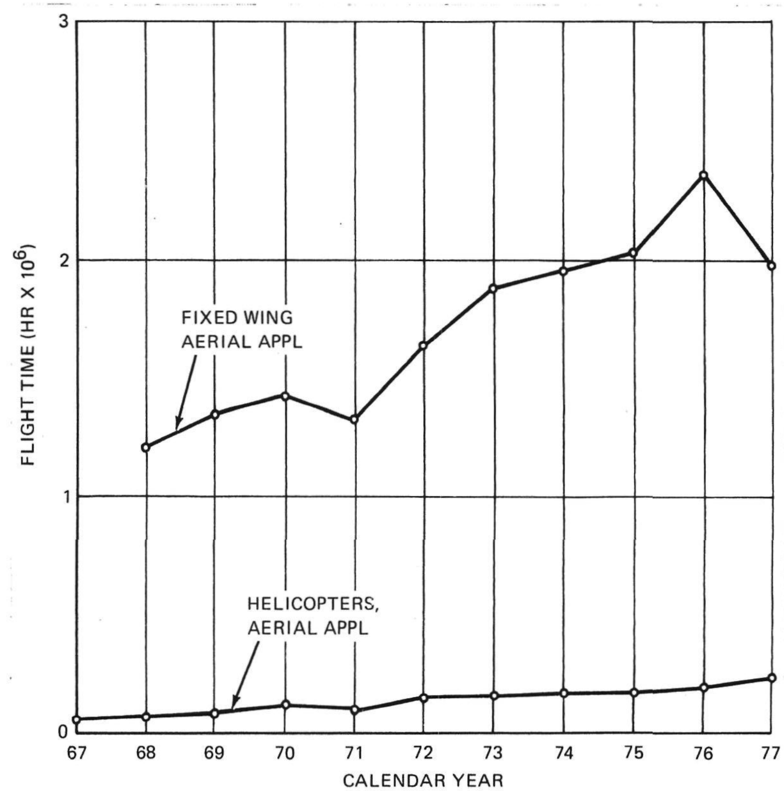


Figure 21. Flight Hours in Millions in the U.S., Aerial Application

Fatalities and injuries can be reduced by designing in crashworthy fuel systems, locating equipment underneath the helicopter to provide energy attenuation, and providing all pilots with flame resistant clothing and crash helmets. A previous study (Reference 11) that reviewed the accident record for all helicopter operations in the U.S. showed that reciprocating-engined helicopters have three times as many accidents as turbine-engined helicopters (i.e., 29.77 accidents/100,000 flight hours for recip's compared to 9.02 accidents/100,000 flight hours for turbines in 1975). This reflects the fact that aerial-application work is done mostly with reciprocating-engined helicopters, and they are included in the data. Public-use helicopters also have a high accident rate, and they are also mostly reciprocating-engined helicopters. Research should be done to solve the reciprocating-engined failure problem, or else turbine-engined helicopters should be used.

3.2 Accident Causal Factors and Potential Solutions

Table IV is a ranking of the prime causes for 197 helicopter accidents in aerial-application work for the three-year period, 1975, '76, and '77. The NTSB recorded 511,481 flight hours for this three-year period for an overall accident rate of 38.5/100,000 flight hours. Pilot errors and material failures were the cause of over 75 percent of these accidents. Collison with wires and poles was the largest single causal factor (19 percent) with engine failures and failing to maintain rotor speed a close second and third.

The large number of collisions with wires and poles again points up the hazardous nature of this type of flying and the need for research into detail causes and possible solutions to the wire hazard problem. Probably pilot fatigue is an important factor in this type of accident. The majority of the engine failures are reciprocating engines (only three were identified as turbines); most of the agricultural helicopters use this type of powerplant at the present time. Discussions with operators indicate that accidents caused by failing to maintain rotor speed are caused by marginal power available in heavily loaded aircraft. A better power match is certainly needed. It is probable that a better power match would also prevent accidents where "misjudged clearance, speed, and altitude" and "collision with trees and ground" are listed as accident causes. These accidents combined are 44 percent of the total, most of which could be related to engine failure or marginal power situations. Therefore, a turbine-powered agricultural helicopter with a good power match could substantially reduce accidents.

Table V lists 109 pilot-error accidents for the three-year period by categories similar to those in Reference 12. The major pilot-error causal factors in agricultural-helicopter accidents are "collision with wires and poles", "failed to maintain rotor speed", "fuel exhaustion", and "misjudged speed and altitude". The main difference between these statistics and those reported in Reference 11, for helicopters overall, is that "collision with wires and poles" is much higher for ag helicopters than the average for all helicopters.

TABLE IV

PRIME CAUSES OF HELICOPTER AERIAL APPLICATION ACCIDENTS (1975, 1976 & 1977)

Accident Prime Cause	Pilot Error	Material Failure	Operations	Maintenance	Undetermined	Totals	% of Total
Collision with Wires/Poles	37					37	19
Engine Failure	1	29		3	2	35	18
Failed to Maintain Rotor RPM	25					25	13
Fuel System (Failures/ Contamination)		3	13	1		17	8
Misjudged Clearance/ Speed/Altitude	13					13	7
Rotor System Failures (Main & Tail)		9		4		13	7
Fuel Exhaustion	12					12	6
Drive System Failures		10		1		11	5
Collision Trees/Ground	8				2	10	5
Improper Operation of Flight Controls	8					8	4
Misc/Undetermined	5	2	4	2	3	16	8
Totals	109	53	17	11	7	197	
Percent of Total	55	27	9	6	3		100%

TABLE V

PILOT CAUSAL FACTORS IN AERIAL-APPLICATION HELICOPTER ACCIDENTS (1975, '76, & '77)

		% of Total
• Incorrect Flying Techniques		
Failed to Maintain Rotor RPM	25	
Fuel Exhaustion	12	
Improper Operation of Flight Controls	8	
Main Rotor Collision With Ground	3	
Hard Landing	1	
Improper Compensation for Wind	1	
	50	46
• Failed to See/Avoid Obstructions		
Collision With Wires/Poles	37	
Collision With Trees/Objects	3	
	40	36
• Error in Judgment		
Misjudged Speed/Altitude	13	
Failed to Use Carb Anti-Ice	1	
Improper In-Flight Decision/Planning	1	
	15	14
• Pilot Fatigue/Diverted Attention		
Takeoff With Spray Gear Attached	3	
Caught Spray Boom on Ground at Takeoff	1	
	4	4
Total	109	100%

Some of the pilot-error problems and possible solutions are shown in Table VI. The number of accidents that can be attributed to toxic chemical inhalation and ingestion with food is unknown. However, when coupled with long hours in a fatiguing environment and a poor visibility situation, pilot errors are inevitable. Pilot-error accidents in civil helicopters are discussed in detail in Reference 12.

TABLE VI

PILOT ERROR PROBLEMS AND POSSIBLE SOLUTIONS

Problems	Possible Solutions
1. Toxic Chemical Inhalation (While Mixing Chemicals, Cleaning Equipment, or Flying Through Cloud).	1. Use a dust mask as required. 2. Cockpit air filtration/air conditioning/ pressurization 3. Fly patterns to avoid chemical cloud.
2. Toxic Chemical Ingestion (Contaminated Food or Liquids).	1. Wash hands thoroughly before eating. 2. Don't eat unwashed vegetables in field.
3. Pilot Fatigue/Discomfort (Long Hours, High Temperatures, High Humidity, Lack of Exercise, Inadequate Rest and Recreation).	1. Get adequate sleep and exercise. 2. Avoid alcohol and drugs and limit coffee intake. 3. Have frequent rest periods, 1.5 hr max between rests; get out of cockpit and exercise. 4. Install air conditioning or seat blowers. 5. Install adjustable-contour seats.
4. Poor Visibility/Sunglare (Dirty Windshields, Flying in Low Visibility/ Poor Contrast Conditions, Inadequate Night Lighting and Cockpit Lighting, and Interior Reflections on Canopy).	1. Clean windshield frequently. 2. Avoid flying in chemical cloud. 3. Exercise more caution if flying into sun. 4. Use sunglasses and visors for sun. 5. Use shooting glasses for poor contrast conditions. 6. Install adequate night flying floodlights and cockpit lighting. 7. Reduce cockpit interior reflections.

4.0 HELICOPTER FORESTRY OPERATIONS

4.1 Background

As the scarcity and the demand for forest products increases, forest management becomes essential. Worldwide, the decimation of forests is occurring at an alarming rate as over-population creates a demand for wood as fuel and building materials. When the forests are cut, soil erosion occurs. This loss of productive soil is coincident with increasing demand for agricultural and forestry products as the population explosion continues. Several solutions to the problems are possible;

(1) Worldwide, drastic reductions in birth rates through population control would curtail the population explosion and thus lessen the demand. (This is probably not possible in time to prevent the problem from reaching crises proportions).

(2) Alternate fuels for the under-developed countries could be provided, and forests could be strictly regulated, worldwide. (This is possible within the next 10 years through use of oil, gas, and coal to provide energy for heating, cooking, and industrial uses in developing countries).

(3) Forest management principles should be introduced worldwide; i.e., all countries should initiate programs for: (1) soil erosion control through seeding grasses and creating water runoff barrriers, (2) forest seeding, (3) application of fertilizer and growth biostimulants to existing stands, (4) application of herbicides to control unwanted brush growth, (5) application of fungicides and insecticides, (6) constant patrol and observation to prevent unauthorized and improper cutting of timber and to provide fire damage prevention. (These things are now being done in the U.S., USSR, Japan, Canada, and other developed countries with reasonable success; what is needed now is more efficient methods of aerial application and continued research in chemicals to minimize the volume and maximize the effectiveness. This will be discussed further in Section 5).

At present the developed countries are using airplanes and helicopters to apply chemicals, to conduct forest management, and to fight fires. They are also using helicopters for logging in inaccessible areas.

4.2 Logging and Firefighting

Logging by helicopter is gaining popularity for hauling valuable timber out of inaccessible areas and over difficult terrain (Figure 22). Helicopters reduce the need for logging roads, which destroy valuable growing land and promote soil erosion. As timber prices continue to increase with demand, this form of logging will become more profitable, and the need for large helicopters with gross weights of 50,000 pounds or more will increase.

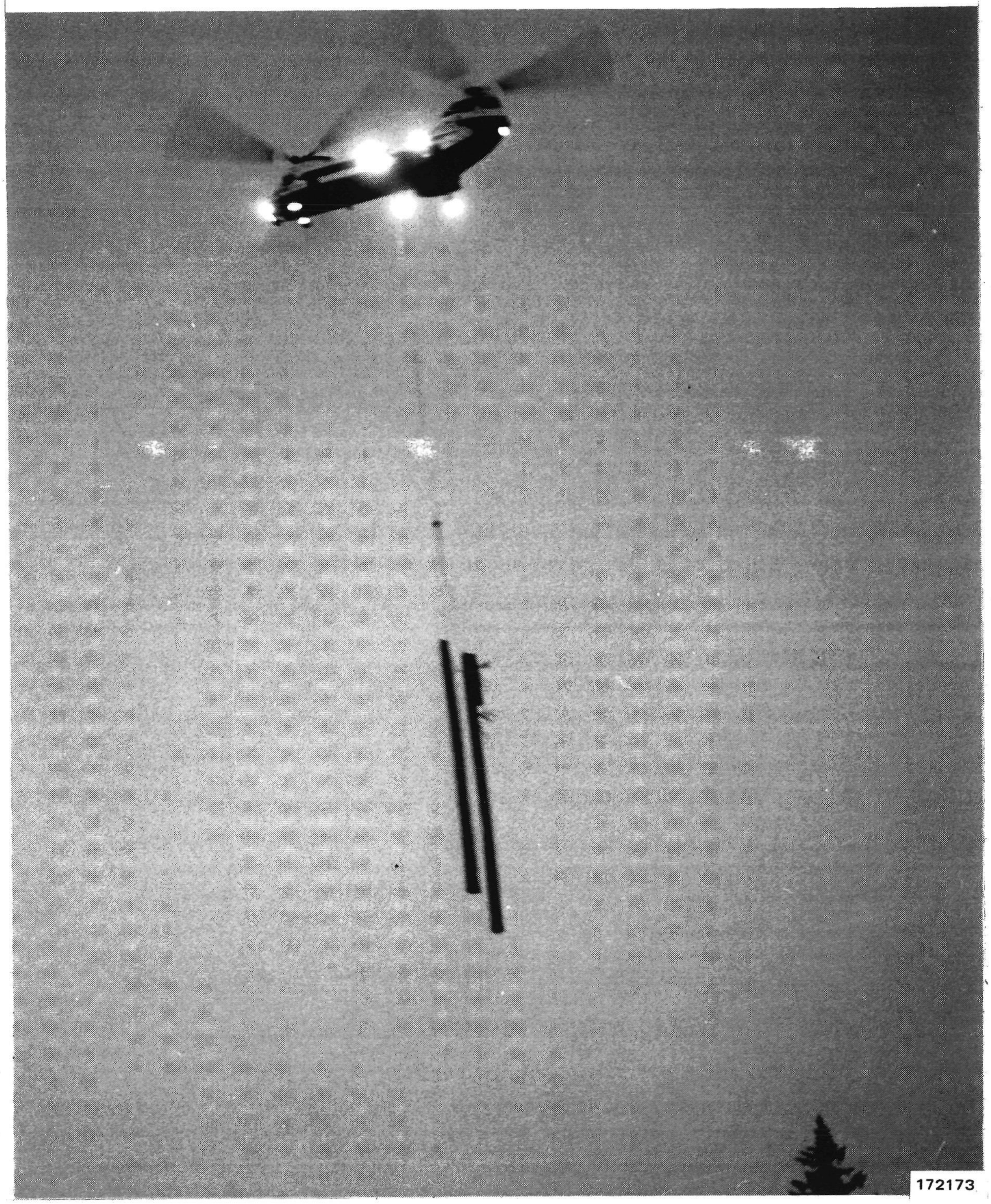


Figure 22. Logging Operations at Night, Boeing Vertol 107-II

As the larger helicopter comes into widespread use, it will be practical and cost competitive for forest-fire fighting. At present, fleets of fire-fighting bombers such as the B-17 and DC-6 are on call to fly to any forest fire site. By the time the airplane is on-site, the fire can be out of control and many valuable acres of timber lost. The problem here is fast response in order to extinguish a fire while it is still controllable and before substantial damage is done.

Helicopters currently used for firefighting are small single-engine aircraft stationed around the country and ready for instant response with small firefighting crews (Figure 23). However, due to their limited capability, fires can get out of control; then bombers, smoke jumpers, bulldozers, and other fire fighting equipment must be called in. As the large helicopters become widely dispersed in logging and construction work, the ancillary job of firefighting can be assigned to these aircraft which can respond within minutes (Figure 24). There are several advantages with helicopters in the 50,000-pound-gross-weight class:

(1) Large cabin size with aft ramps for rapid loading of crews and fire-fighting tools and equipment.

(2) External cargo hook for transporting small bulldozers, firefighting pumps, chemicals, and 20,000-pound fireretardant buckets. The fire retardant can be dropped accurately in various quantities to provide the most effective fire extinguishing capability.

(3) Medical evacuation capability including emergency medical care on-board with multiple litters.

Figure 23. Hiller 12E Refilling Water Bucket During Firefighting Operations

(4) Can be used as flying command post equipped with Forward-Looking InfraRed (FLIR), precise navigation systems, telemetering, and other communcation systems for directing firefighting efforts.

The present method of helicopter logging requires an on-site firefighting capability in constant readiness, and the forest service can capitalize on this by contracting for emergency fire fighting "on call" with a set response time. Logging crews could have special training as standby firefighters. More use of helicopters in this secondary role will reduce the number of standby single-use airplanes needed worldwide. Maintaining fleets of single-use, under-utilized airplanes is not cost effective. The argument against the use of large helicopters has always been the high acquisition and maintenance costs as compared to World War II vintage bombers and transport airplanes. The key to helicopter usage is high utilization, multiple-use helicopters widely dispersed throughout the forest areas of the world. The operations of forest logging and firefighting over all types of terrain requires the safety afforded by large, powerful, twin-turbine helicopters. External lift is also desirable for the emergency jettison capability. Any heavy load of chemical retardants carried internally takes up valuable cabin space and requires emergency dumping apparatus. Since the helicopter can reload retardants from trucks near the site or reload with water from nearby lakes, the slower speeds associated with carrying external buckets is not a significant drawback compared to the benefit of versatility.

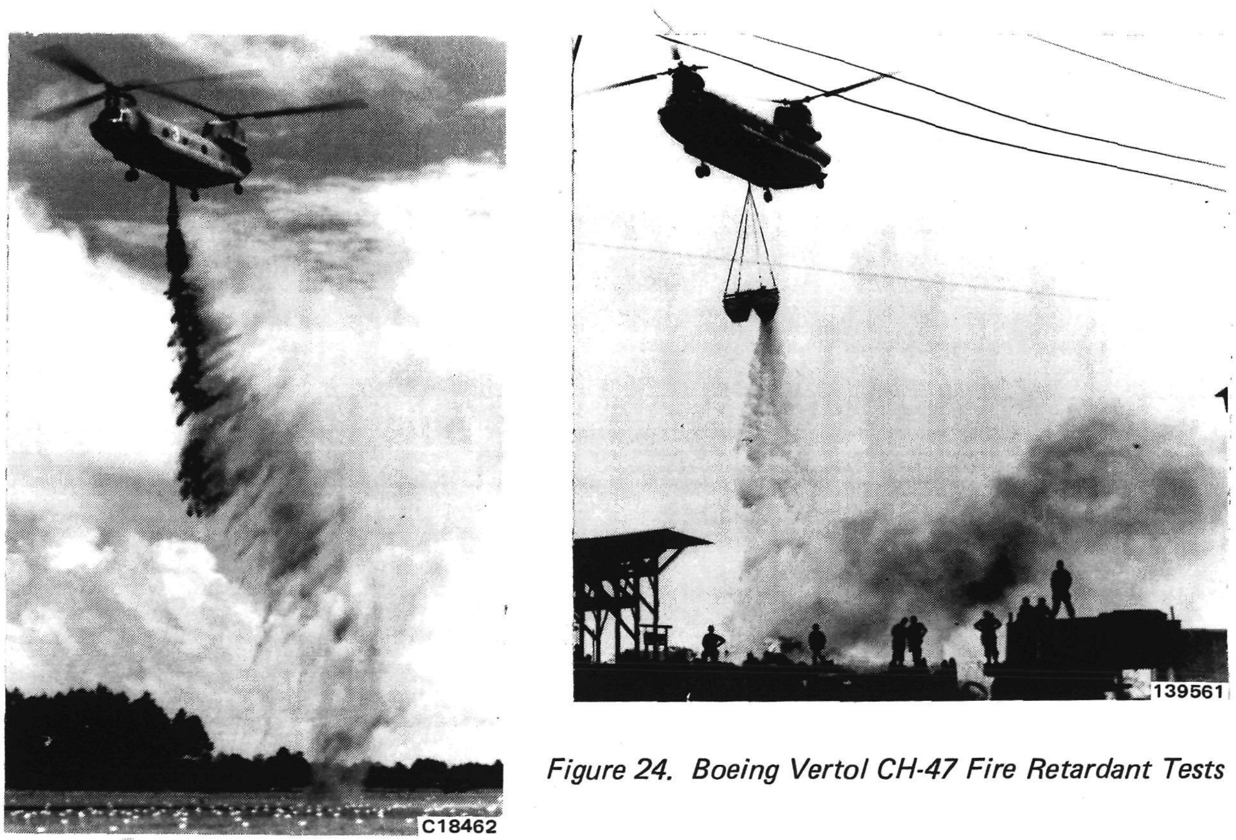


Figure 24. Boeing Vertol CH-47 Fire Retardant Tests

The ability to rapidly and accurately place heavy firefighting equipment, crews, and fire retardants and to conduct medical evacuation, fire surveillance, and supervisory activities is within available technology with current helicopters.

4.3 Aerial Application on Forests

To date, testing of large scale application in forests has been limited. Most work so far has been done by small helicopters on small forests with insecticides and fungicides at rates of 5 to 10 gallons per acre. These operations with single-engined helicopters are hazardous and cost on the order of $10 per acre. In future, much larger twin-turbine-engined helicopters will be required to handle forest acreages of several hundred to several thousand acres at high application rates. Fertilizer (forest grade urea) is applied at 440 pounds per acre. The first application is when the trees are 15 to 25 years old, the second 5 to 10 years later, and the third 5 years after that. These applications can be planned so that they are essentially off-season or during lulls in logging and firefighting operations. The increase in utilization through multiple uses can materially reduce costs which are very sensitive to utilization. This is discussed in Section 5.

The typical Douglas fir tree growth cycle involves the following:

(1) Clear-cut the forest
(2) Application of a desiccant for drying out
(3) Controlled burning of bush and logging residue
(4) Planting by hand or by aerial means
(5) Application of herbicide to control bush and grasses
(6) Thinning by chain saw or chemical means
(7) Application of herbicides to kill off alder
(8) Application of insecticides and fungicides throughout the growth cycle, as required
(9) Application of fertilizer, as appropriate, during growth cycle

4.4 Future Trends

In summary, it is evident that the future for forestry helicopters will lie with large, twin-turbine helicopters with multiple uses: (1) logging, (2) firefighting, (3) seeding, (4) application of pesticides, fungicides, herbicides and fertilizer, (5) construction work. Versatility is the key to high utilization which in turn lowers operating costs. The impact of high utilization on operating costs and research-and-development needs for higher productivity are discussed in Section 5. There will of course be a constant demand for smaller single-turbine-engined helicopters on standby for initial firefighting and surveillance duty, as well as for aerial application on small forests and tree stands.

5.0 COST BENEFITS ANALYSIS

5.1 Costs of Aerial Application

Costs to the growers for aerial application by helicopters were obtained from interviews with a number of operators. In some cases the operators requested that these costs not be identified with them. Therefore, the cost per acre scatterbands represent all types of crops in all types of locations and subject to wide variety of field conditions. Variables include the following:

1. Small, medium, and large fields ranging from less than 20 acres to over 500 acres.

2. Populated congested areas with numerous obstacles such as wires, poles, trees, etc.

3. Terrain ranging from flat to hilly to mountainous.

4 Elevations from sea level to 5000 feet and temperatures from cold to 100°F and sometimes higher accompanied by high humidity.

5. Crops that include grasses, field crops, vegetables, berries, orchards, and citrus.

6. Chemicals such as insecticides, herbicides, and liquid and dry fertilizers.

Figure 25 shows the dollar-per-acre charges to the grower excluding the cost of chemicals, for application of liquid chemicals by helicopter. At the upper side are herbicides, while insecticides, fungicides, and fertilizers have lower application costs. A substantial separation exists between tree crops (orchards and citrus) and row and field crops. Tree crops require higher application rates and deep penetration by helicopter downwash. Therefore, slower pass speeds are shown (approximately 30 mph), and productivity runs from 60 to 80 acres per flight hours depending on application rate which ranges from 10 to 40 gallons per acre. Herbicide application is more expensive because the operator must have special insurance against overspray and drift, and the extra care taken in spraying results in lower productivity.

Figures 26 and 27 show some costs of application by airplane for a rough comparison. These data represent a very narrow cross section, but they do illustrate that application costs by airplane run a little lower than by helicopter. Several helicopter operators commented that airplane charges run \$.50 to \$1.00 less than by helicopter on similar crops. Others said that they operate both helicopters and airplanes, and charge the same for each but that they select the type of aircraft depending on ferry distance, type of crop, field size, type of chemical, and what the customer wants. The trend toward larger faster helicopters seems to result in a more competitive operation.

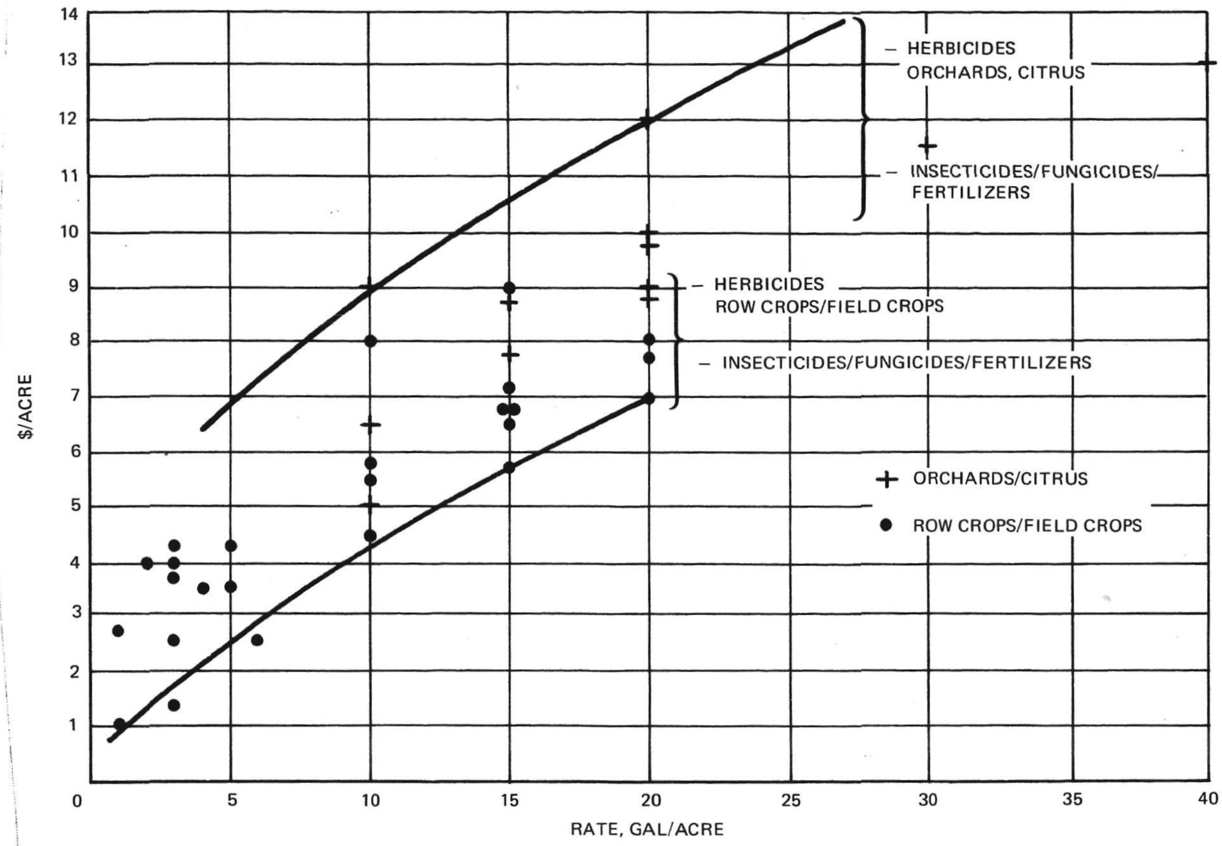


Figure 25. Cost of Application of Liquid Chemicals by Helicopters

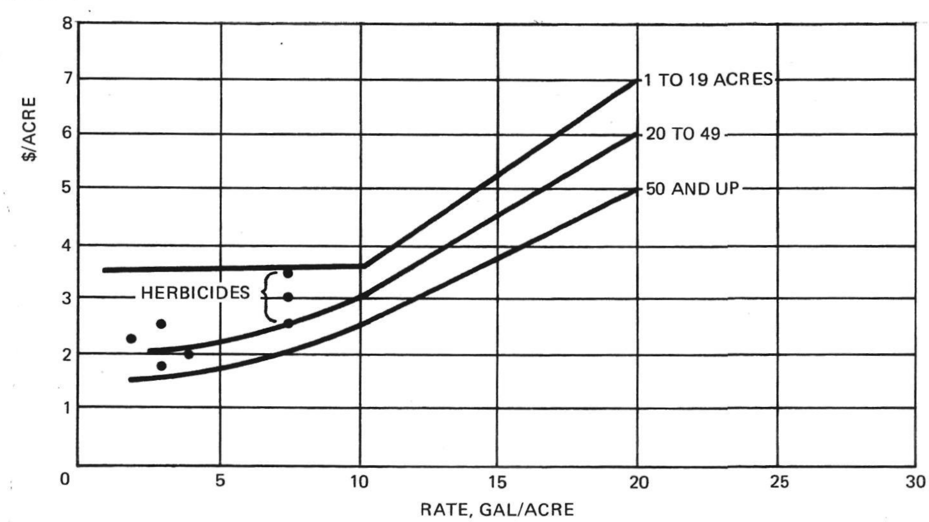


Figure 26. Cost of Application of Liquid Chemicals by Airplane

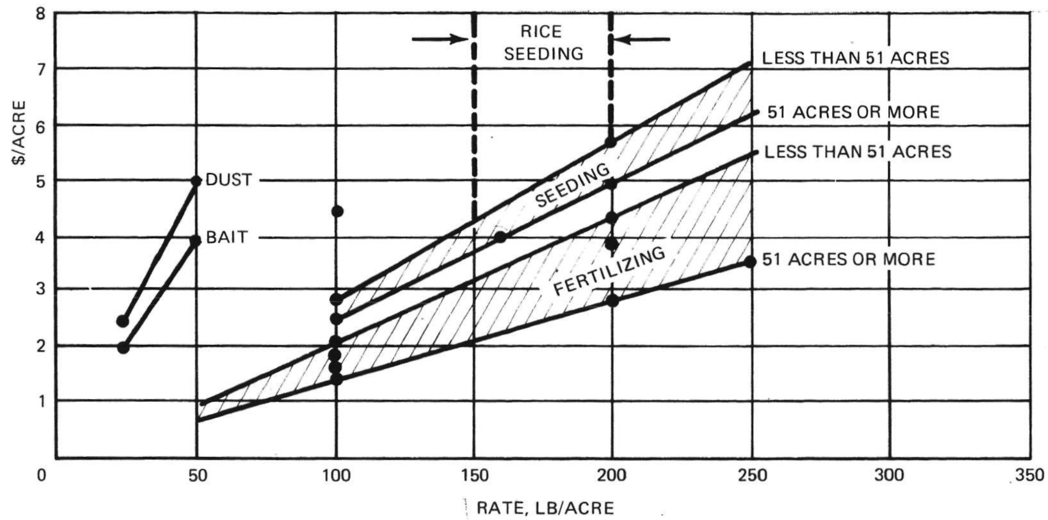


Figure 27. Cost of Application of Dry Chemicals and Seed by Airplane

Figure 28 shows the productivity in acres per flight hour that is being achieved with helicopters plotted against application rate. As can be seen the preponderance of points falls between 60 and 100 acres per flight hour at rates of 5 gallon per acre and above. The few points above 100 acres per flight hour are for very low application rates or larger helicopters. These data are based on monthly or yearly total acres and total flight hours and an estimated average application rate. The average overall productivity for helicopters in the U.S. is approximately 80 acres per flight hour. This is not surprising since 80 percent of the fleet is made up of Bell 47's and derivatives and Hiller 12E's. Larger and faster helicopters will raise the acreage in the future.

Figure 29 shows the average costs per acre versus productivity in acres per flight hour. The higher costs are generally associated with higher application rates, but it is not possible to construct a meaningful scale showing the application rates because of the wide variations evident in the figure. It is clear, however, that costs decrease dramatically when productivity is increased between 50 acres per flight hour and 150 acres per flight hour. As discussed above, productivity in orchards and citrus groves cannot be significantly increased because slow speeds and powerful rotor downwash are required for trees. Major areas of potential productivity improvement are in row crops, field crops, and forests for all types of chemicals and seeding.

Liquid spraying productivity is improved most by higher gross weight helicopters because:

- Increased payload results in more area coverage without reloading,
- Wider swaths can be achieved by using more powerful downwash and tip vortices combined with longer spray booms, and
- Larger helicopter have higher speed capability.

However, higher speeds and gross weights result in increased turn time, so high speeds are most effective in reducing ferry time and run time on longer fields.

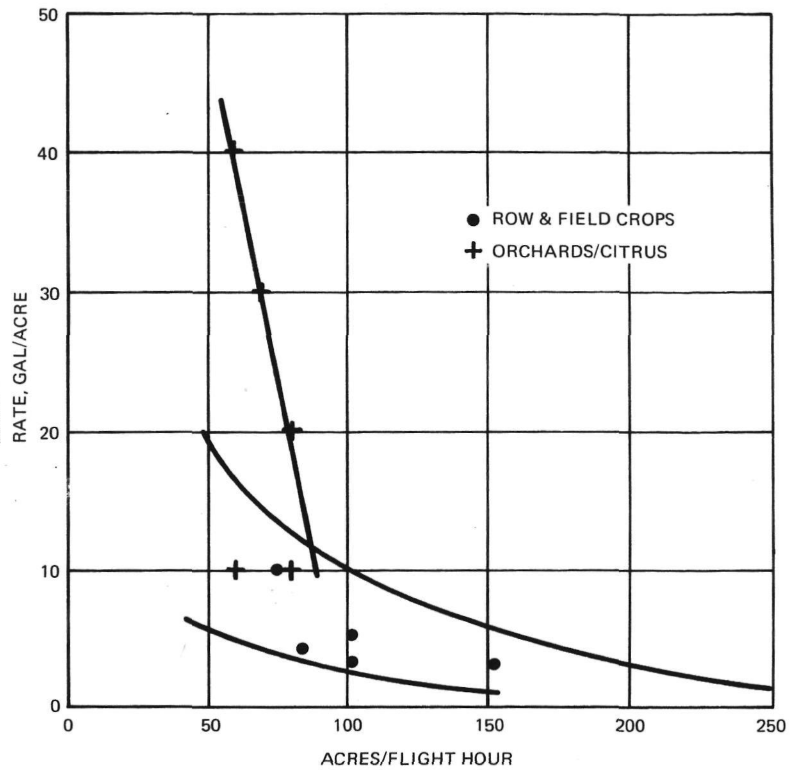


Figure 28. Helicopter Application Rate versus Productivity

For dry materials, higher gross weight helicopters also increase productivity, but care must be taken to avoid downwash impingement on the chemicals, which are usually granular and are applied by slingers or venturi devices. Downwash impingement can restrict the maximum swath width achievable and cause uneven dispersion.

5.2 Ferry Distance Considerations

A constant consideration of aircraft operators when determining the cost per acre of a particular job is the ferry distance. Ferry time can run operating costs to extremes and can even cause a loss of profits if not treated carefully. In many cases ferry time can be offset by high acreage, but in the case of long ferry distance and small acreage, other means of ensuring profits must be found. One way of maintaining profits would be to charge a standard rate for hours or miles incurred in going to and from a job. Another way would be to require a minimum fee for fields outside of a predetermined radius. A third way would be to increase rates per acre within various radii of the base of operations.

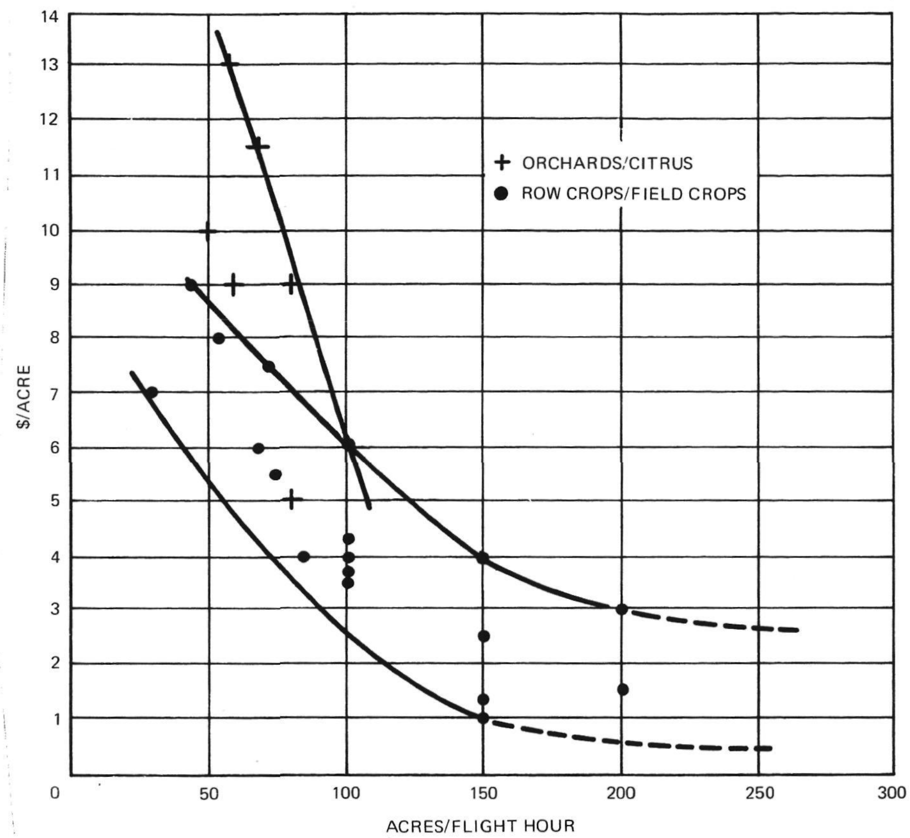


Figure 29. Average Helicopter Cost/Acre versus Productivity

Figure 30 shows how a typical operator determines how far he can ferry to a job without increasing the costs to his customers. Plotting acres per flight hour against acres per field results in a curve showing the minimum acreage required to make a profit when traveling a ferry distance of 7.5, 15, 25, or 35 miles. The break-even point for this operator is 60 acres per hour; above this point is profit and below this point is loss. If a job falls below the break-even point, the operator then uses Figure 31, which gives additional charges per acre for ferry distances of up to 35 miles. That is, if the operator has a 175-acre field 15 miles away, he would average 62 acres per hour and be above the break-even point; therefore a base charge of $3.50 per acre would be made to the customer. If the operator had a 100-acre field, he would average only 53 acres per hour and an additional charge of $.50 per acre would have to be made.

5.3 Productivity

The subject of absolute and relative productivity is discussed in Reference 13.

NOTE: Paragraph 1.2.8, pages 22 through 27 of Reference 12, on agricultural helicopter use in the USSR, was obtained through a translation by W. Z. Stepniewski and is included in this report as Appendix A.

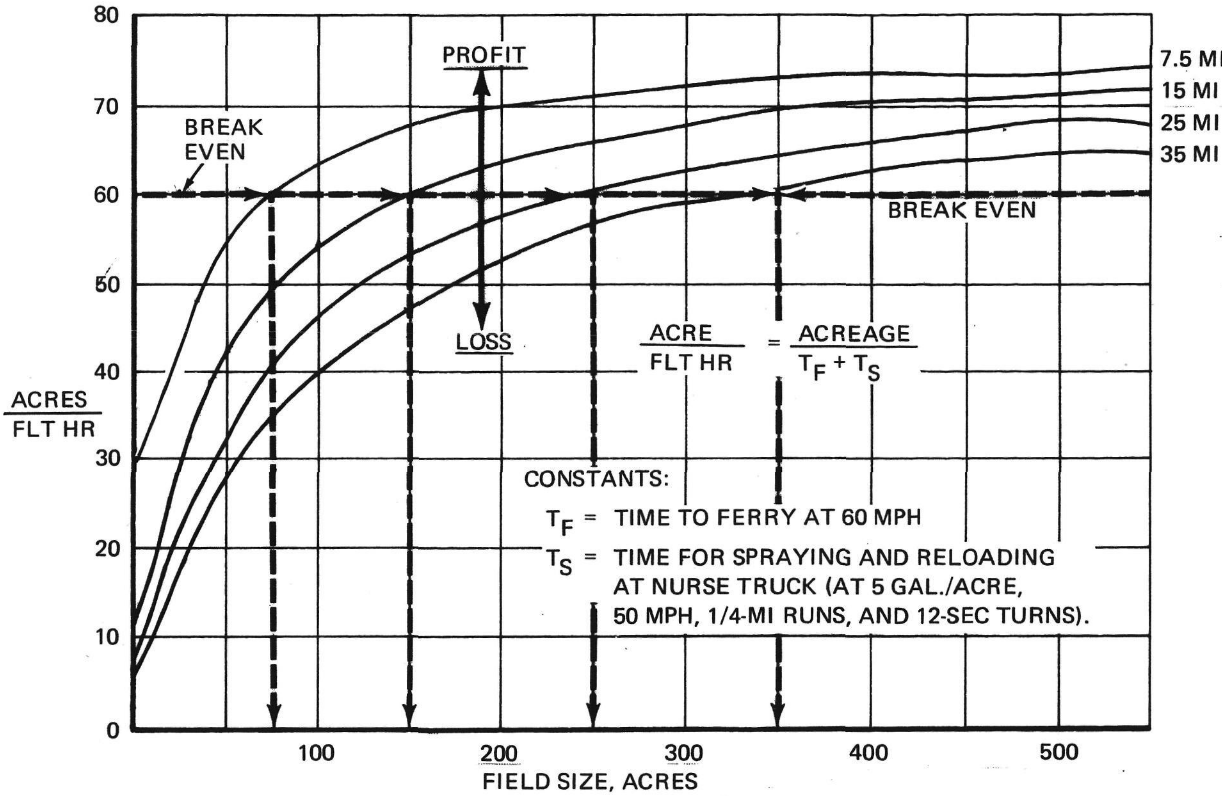


Figure 30. Sensitivity of Helicopters to Ferry Distance

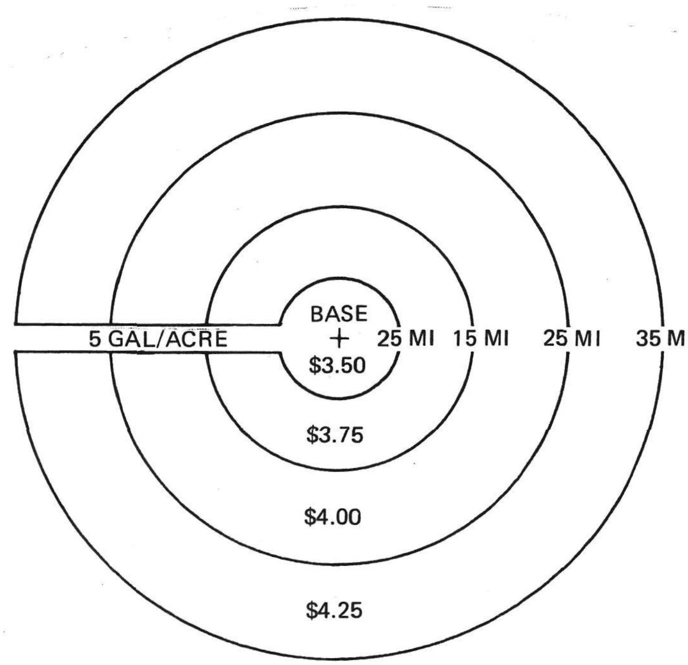
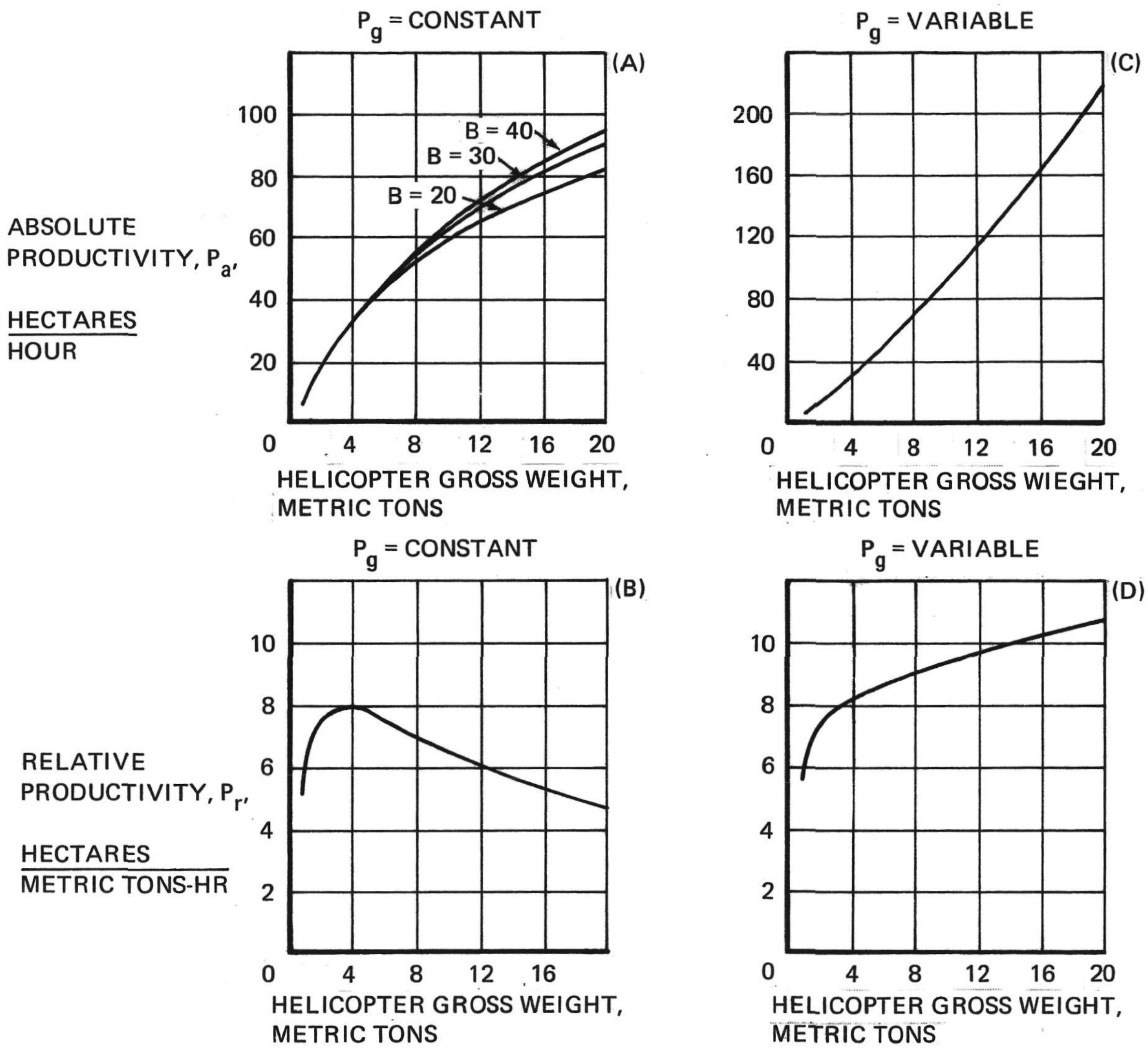


Figure 31. Ferry Compensation Charges Per Acre

The authors discuss improving productivity of helicopters that were adapted for agricultural work in the USSR. The use of helicopters in the USSR is expanding all the time. (In a recent trip to the USSR, Dr. Bruce Holmes of NASA Langley was told that about 15 percent of the aerial-application work in the USSR is by helicopter.) The authors develop equations for calculating productivity based on factors that affect cycle time, such as swath width, payload, speed, ferry distance, and loading time. The translated explanation of the results of the calculations shown in Figure 32 follows:

> The results of calculations based on the equations are shown in Figure 32. In these calculations the helicopter gross weight varied from 1 to 20 metric tons (2,200 to 44,000 pounds). The pass length was assumed as 1 kilometer, and the ferry distance from the base was 3 kilometers. Fertilizer application norm was 0.3 tons per hectare (260 pounds per acre). The speed was taken as 120, 130, 150, 170, and 200 kilometers per hour (72, 78, 90, 104, and 120 mph respectively) for gross weights of 1, 2, 6, 12, and 20 metric tons. Absolute productivity (hectares per flight hour) is shown in Figure 32(a) for weights and speeds indicated above for three values of the swath width (B = 20, 30, and 40 meters) and under the assumption that the loader productivity is 50 metric tons per hour. Figure 32(b) shows the relative productivity (absolute productivity divided by gross weight) for the swath width, B, constant at 40 meters. It can be seen from Figures 32(a) and (b) that the absolute productivity steadily increases with gross weight, while the relative productivity has a maximum for a gross weight equal to about 4 metric tons.
>
> If we assume that with the increase of helicopter gross weight, width of the swath and productivity of the ground loader also increase, then the absolute productivity of the helicopter increases with increase of gross weight, as shown in Figure 32(c). In this case the relative productivity (Figure 32(d)) also increases with increase of gross weight. However, for helicopter gross weights higher than about 4 metric tons, the rate of increase of relative productivity diminishes.

The significance of these curves to the U.S. helicopter industry is that to date we have paid little attention to the high-rate application of dry fertilizers. As noted in Section 2.9 some work is being done at 440 pounds per acre but only on a small scale. The curves of Figure 32 show that absolute productivity (hectares per hour) increases steadily with gross weight, but relative productivity (hectares per hour per gross weight) peaks at 8,000-pound to 9,000-pound gross weights. Typical acres per flight hour from Figure 32(b) for a 9,000-pound-gross-weight helicopter flying at approximately 80 mph with a swath width of 65 feet at an application rate of 260 pounds per acre is 35 hectares per hour (87 acres/hour). Compare this to the slinger bucket operation in Canada flying at 70 mph at effective swath widths of 65 feet and application rates of 440 pounds per acre with a Bell 205 which can cover 70 acres per flight hour. Higher acres per flight hour can be achieved by minimizing loading time through use of two buckets, one of which is loaded while the other is being emptied. This method could accommodate two helicopters using three buckets for maximum efficiency on very large jobs.



P_g = GROUND LOADING PRODUCTIVITY

B = SWATH WIDTH IN METERS

1 HECTARE = 2.47 ACRES

Figure 32. Influence of Gross Weight on Absolute and Relative Productivity (USSR)

Some general observations made in Reference 13 are:

1. From a productivity viewpoint, optimal speeds are higher than normal helicopter speeds now flown.

2. Wider swaths increase productivity.

3. Longer pass lengths increase productivity.

4. Higher application rates decrease productivity.

5. Longer ferry distance decrease productivity.

6. The Russian helicopter industry believes that as yet there is no serious need for a specialized ag helicopter because of the advantages of multi-use and off-season utilization. Lower helicopter acquisition costs result from multi-uses because of larger production runs.

7. Hanging spraying equipment externally on existing helicopters appears to be a significant drawback of the established practice because of high drag and consequently lower speeds.

The Russian report seems to agree with the opinions of many helicopter operators and helicopter manufacturers in the U.S. meanwhile:

1. Fixed-wing operators are going for higher payloads and higher speeds although they want to retain a lower speed capability for reduced turn time and where better spraying control is needed. The Eagle airplane with low drag, low wing loading, and a high aspect-ratio wing is an example of this.

2. Fixed-wing operators are gearing up for high application rates (400 to 500 pounds per acre) in competition with ground application equipment (high speeds and high gross weights).

3. Fixed wings are continuing to be specialized aircraft, going for low drag, lightweight turbine power, integral spraying and dusting equipment, with pilot safety features and creature comforts such as air conditioning.

5.4 Utilization

Helicopter utilization has a significant effect on the cost of aerial application and consequently the profits of the operator. Figure 33 shows only the effects of the acquisition cost, annualized at 1 percent per month of the aircraft value, added to the hull insurance costs, assumed at 10 percent per year for that same aircraft. These curves would be applicable only to helicopters because the hull insurances rates would probably be a lower percentage for airplanes. What Figure 33 shows is that for any utilization below 300 flight hours per year, the increase in costs per flight hour is dramatic. By 500 flight hours per year the costs are pretty much leveled out. Another significant point revealed by these curves, as many operators have discovered, is that more expensive aircraft are more sensitive to utilization. The small operator with low overhead and low-cost surplus aircraft does have the advantage of a low cost operation. Based on this analysis it would appear that turbine helicopters would not be cost effective. However, the factors of higher utilization because of versatility, and higher productivity at altitudes and temperatures combined with increased safety with newer turbine helicopters largely offsets this apparent disadvantage. It does illustrate that the small operator starting out with surplus helicopters can be competitive in small fields and at low application rates. The key issues with older reciprocating-engine helicopters are spare parts availability and higher accident potential.

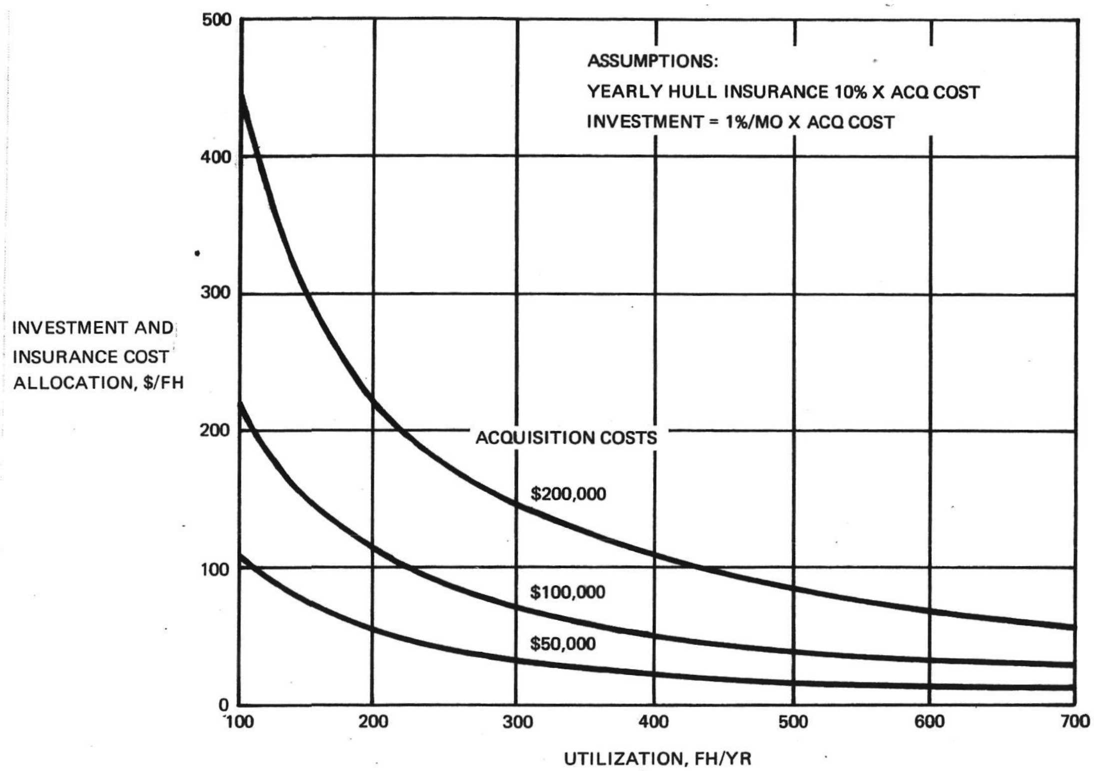


Figure 33. Variation of Investment and Insurance Costs With Utilization

6.0 FUTURE PROJECTIONS AND MARKET NEEDS

6.1 Future Projections

As a result of operator surveys and analyses some projections as to future needs in agricultural and forestry helicopters are outlined in this section. Many of the aerial-application needs are similar in agriculture and forestry and are complementary in that work in forestry can be done at a different time than at the peak of the crop growing season. At the present time there is not a heavy competition between ag helicopters and ag airplanes because the market is still expanding rapidly (estimated at over 10 percent per year). Both airplane and helicopter manufacturers are busy trying to keep up with sales. The fact that many of the airplanes and helicopters are obsolete, are operating with inefficient payload capability because of inadequate powerplants, and have excessive drag penalties is offset by low direct operating costs. Most operators are working hard and making a reasonable profit, providing they have not been caught up by a bad accident record.

The increasing demand for aerial application to replace ground application has resulted in the more progressive and innovative operators trying out new techniques and modifying equipment to adapt to peculiar needs and get the highest productivity for the lowest cost. Many ag-airplane operators are seeing the need to augment their fleets with helicopters and finding that a mixed fleet makes sense and permits taking jobs where the airplane is inefficient (i.e., long ferry distances, small fields with difficult terrain and obstacles, frequent fog and low visibility, frost control, congested population areas, and in orchards and citrus groves). The helicopter usually is a two-seater which can be used for public relations and survey work. The off-season work can turn a marginal profit operation into a highly profitable one by simply increasing utilization to offset overhead and other fixed costs. The future for the ag helicopter is clearly upwardly mobile, and new uses are developing constantly.

6.1.1 Agriculture

It seems likely that the helicopter will rapidly increase its ratio to the airplane. The 1:10 ratio will rapidly increase as the smaller obsolete airplanes are displaced by small helicopters with 1,000-pound to 2,000-pound payload capability at density altitudes of 3,000 to 5,000 feet. These helicopters will probably have the characteristics shown in Column 1 of Table VII. Note the multiple uses which are essential to increase utilization and keep costs competitive with ag airplanes.

6.1.2 Agriculture and Forestry

Column 2 of Table VII shows the characteristics needed in a medium-sized helicopter that can be used for application of fertilizers, insecticides, fungicides, and herbicides at high rates on large forests and fields. This size helicopter can also be used for logging; construction, transporting firefighting crews, equipment, and fire retardants, and offshore drilling rig support. Several helicopters are being used for these purposes now and can be used for liquid application and high-volume spreading of fertilizers by adapting spray equipment and slingers either on buckets or on the bottom of the aircraft.

6.1.3 Forestry

Column 3 of Table VII shows medium to large helicopters that are oriented for large-volume application of fertilizers and insecticides and used for transporting firefighting equipment and fire retardants. Figure 34 is an artist's renderings showing future uses of the large helicopter in logging.

TABLE VII

FUTURE NEEDS IN AGRICULTURE/FORESTRY HELICOPTERS

Characteristics	Small	Medium	Large
Gross Weight (External)	3,500	8,000-20,000 lb	20,000 to 50,000 lb
Payload at 3,000 Ft Hd	1,500	4,000-10,000 lb	10,000 to 25,000 lb
Gross Weight (Internal)	3,200		
Payload at 3,000 Ft Hd	1,200		
Seating	(2) Pilot + (1) Pass.	2-6 Passengers	25-44
Ferry Speed			
No External Equipment	125	145	150-175 mph
Spray Config	100+	120	120
Spraying Speed, Mph	30-100	30-100	30-100
Engine	(1) Turbine	(1 or 2) Turbine	(2) Turbines
Power Takeoff	10 Hp (Hyd/Elect.)	45 Hp (Hyd/Elect.)	45 Hp (+)
Optional Equipment			
• External Cargo Hook	x	x	x
• Air conditioning/Filtering/ Cockpit Pressurization	x	x	x
• Engine Air Particle Sep	x	x	x
• Litter Provisions	Int & Ext	Internal	Internal
• Logging Hover Controls	N/A	x	x
Principle Work			
• Application Wet/Dry	x	x	x
• Forest Fire Fighting Support	x	x	x
• Logging and Support	x	x (Twin)	x
• Public Use (Police/Fire/Ambulance)	x	x	x
• Offshore SAR	N/A	x (Twin)	x
• Construction	N/A	x	x

Figure 34. Boeing Vertol 234 Logging Operations

6.2 U.S. Market Needs

There are two factors that influence the need for helicopters in this work in the U.S. The first is that for a given payload the cost of helicopter operations (acquisition, maintenance, and insurance) is higher than for the airplane. This must be made up for by higher productivity or specialized application in small congested fields and crop variables. The second factor is that the small reciprocating-engined helicopters are inefficient and underpowered and should be replaced in many operations. The helicopter must increase productivity through higher swath widths, higher speeds, and increased payloads if it is to increase its share of the market.

Reference 14 projects the U.S. fleet of agricultural helicopters increasing from approximately 1,100 today (1979) to 3,600 by the year 2000 (Figure 35 taken from Reference 10). This equates to about 10 percent of the total U.S. aircraft fleet today, and 20 percent by the year 2000. This fleet will probably require about 3,000 new and remanufactured helicopters in the next 20 years. Figure 36, also taken from reference 14, shows the nominal world ag aircraft shipments from 1961 to present and projected to the year 2000. Free World and Communist nations are compared. Of special interest in this study is the free world projection for helicopters which will require a total of about 6,000 new and remanufactured units in the next 20 years. Additional requirements for helicopters for forestry aerial application, firefighting, and logging will increase the U.S. and free world projections significantly.

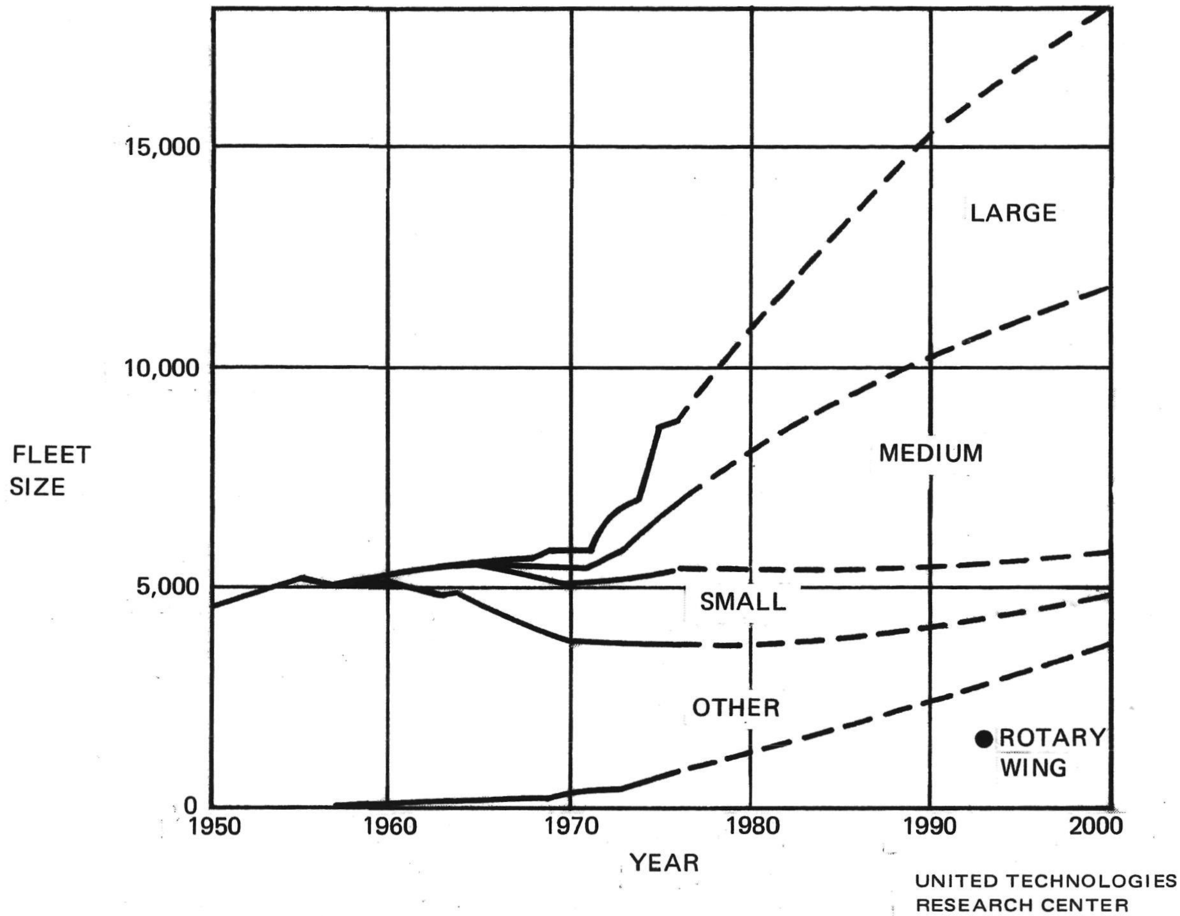


Figure 35. Nominal Projection of U.S. Agricultural Aircraft Fleet

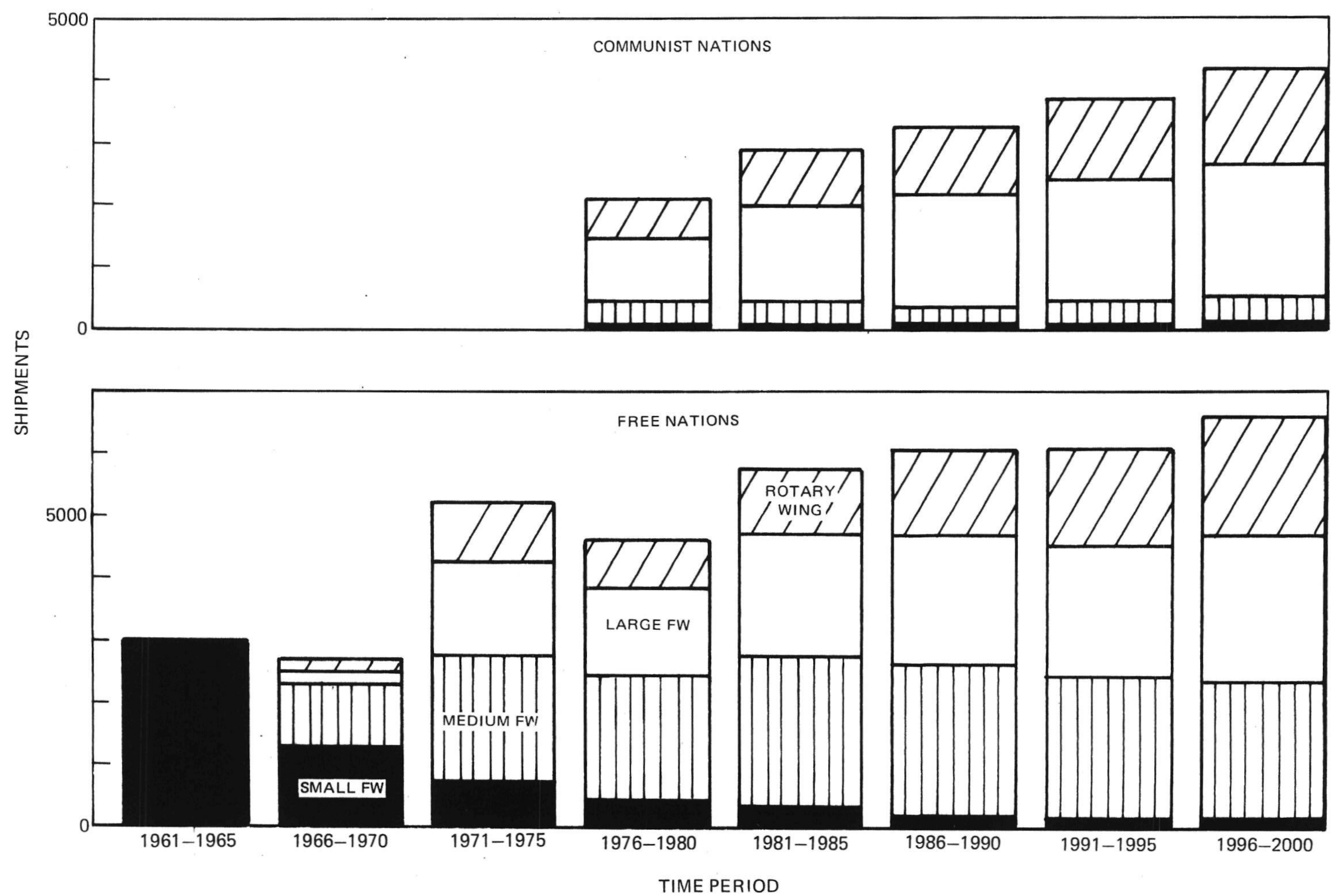


Figure 36. Nominal Projection of Agricultural Aircraft Shipments by Type

7.0 HIGH PAYOFF RESEARCH EMPHASIS

7.1 Potential Helicopter Technology Benefits

Table VIII lists areas of technology and potential benefits from research in these areas for agriculture and forestry helicopters. Certain shortcomings can be partially overcome within current technology; increased payload, speed, and high/hot performance, and crash survivability improvements are examples that need special application to ag helicopters. Research requirements are noted in Table VIII. The needs are listed in the approximate order of importance in the opinion of the author. A level of need is stated where 1 is most needed and 3 is least needed. High-payoff research needs are discussed in the following paragraphs.

1. Pilot Error Accidents - Errors in judgement such as: flying into known wires or obstacles; misjudged clearance, speed, and altitude; failed to maintain rotor speed; and fuel exhaustion all point to pilot inattention or fatigue. This hazardous demanding job needs more study as to what can be done to reduce pilot errors, which cause 55 percent of the accidents.

2. Wire Strike Problem - A better understanding of the wire-strike problem is needed since they cause 19 percent of the accidents. In many cases the pilot is aware that wires are present but still flies into them because of inattention, poor visibility, or possibly lack of reserve power in turns.

3. Reciprocating-Engine Failures cause 18 percent of the accidents. The trend to turbine engines and a better power match will help alleviate engine failures. However, continued research in turbine engines is needed for improved reliability and reduced maintenance costs. Very little research, if any, is being done on reciprocating engines.

4. Improved Spray Booms and Spreaders are needed in conjunction with research on higher gross weight helicopters. The spraying speed, height above the crop, rotor disc loading, downwash, and spray boom/spreader design relationships still need work to achieve highest productivity. The variety of materials and wide variation in application rates make this a formidable task.

5. Automatic Flagmen and Navigation Systems such as Del Norte, Minneapolis-Honeywell, and Loran could have a significant impact on large field operations by providing improved accuracy while eliminating need for flagmen.

6. Night Application has been done successfully and has advantages in low temperatures and low winds which improves payload and reduces drift. Insect kill is improved and evaporation is reduced, which conserves chemicals. Proper lighting is required and becomes more

TABLE VIII

POTENTIAL HELICOPTER TECHNOLOGY BENEFITS

Technology	Benefits	Level of Need*	Research Needed
1. Increase Payload/Speed/ (High/Hot) Performance	• Increase productivity • Reduce application cycle time • Reduce ferry time • Penetrate larger field market • Can handle high-application-rate jobs • Increases safety/power margin	1	Yes - Current turbine-engine technology will improve. Further research needed to improve turbine-engine efficiency and reliability and to utilize lightweight structure.
2. Improve Engine Reliability	• Reduce power failure accidents • Reduce maintenance & overhaul costs	1	Yes - Reciprocating engine failures cause 16% of accidents & turbines need improvement.
3. Improve Crash Survivability • Fuel Containment • Lightweight Helmets • Landing Gear Energy Absorption • Airframe/Seats Energy Absorption	• Reduce costs of crashes • Decrease fatalities & injuries	1	Yes - Apply existing technology but additional research needed to develop new crashworthy structures for further improvement.
4. Human Factors - Pilot Fatigue • Noise, Vibration, Heat, & Humidity • Long Working Hours • Seat Comfort • Toxic Chemical Ingestion/Inhalation	• Reduce pilot-error accidents • Reduce wire & obstacle strikes • Reduce fuel exhaustion accidents	1	Yes - Pilot errors cause 55% of accidents; ways to reduce this type of accident need to be defined and developed.
5. Improved Spray Boom & Spreader Design • Droplet Size Control • Slingers - Smooth Particle Acceleration	• Increase swath width • Take on high-rate jobs seeding/ fertilizing • Less chemical waste & drift • Low application rates	1	Yes - Matching spray booms and spreaders to cargo helicopters. Study effects of wind currents in heavy tree foliage.
6. Helicopter Downwash/ Speed/Height Above Crop Relationship	• Increase swath width • Reduced application rate • Improved uniformity of application • Improved canopy penetration	1	Yes - Trend to larger helicopters dictate need to understand these interactions.
7. Improved/Automated Guidance	• Reduced flagman costs & hazards • Accuracy & uniformity of application	1	Yes - Continued improvement on low-cost systems.
8. Night Flying Visibility Aids, Lights & Navigation, Shadow Contrast	• Increased utilization of aircraft • Increased payload (cool temp) • Less drift (low wind/less gusts) • Less evaporation/lowest application rate	1	Yes - Night navigation, visibility, and lighting to ensure accuracy; determine which insecticides are more effective at night & how to reduce application rates.
9. Conversion Capability/ Flexibility from Dry to Liquid	• Increased utilization • Increased productivity	2	Yes - Especially in larger helicopters.
10. Controls/Visibility/ Seating Improvements for Logging & Construction	• Reduce pilot fatigue • Increase safety • Increase productivity	2	Yes - Flying the external load will be even more demanding in larger helicopters.
11. Develop Chemical Batch Mixing Concepts (Centrals)	• Reduce hazards to personnel • Reduce spill hazards of concentrated chemicals • Reduce disposal & decontamination of numerous small containers	2	Yes - Develop pilot plant for evaluation.

*Level of Need: 1 Most, 3 Least

critical at high speeds. Navigation can be more difficult and fog can be a problem, so application techniques need to be worked out. The limitations in flying uneven or mountainous terrain at night may preclude this mode, but it should be tested.

7. Quick Conversion from liquid to dry materials needs to be explored further to minimize time wasted in changeover.

8. Pilot station requirements for logging operations have been solved in existing helicopters by providing side window bubbles so that the pilot can "fly the load" at all times while the copilot is "heads up" most of the time and monitors air speed and subsystem instruments. As larger more productive helicopters come into use in logging, firefighting, and other operations requiring accurate placement of heavy external cargo and equipment, the demands on pilots will increase. Research is needed to optimize the crew station for pilot comfort, visibility, and endurance.

9. Chemical batch mixing offers efficiency, reduces hazards from chemical handling spills, minimizes contaminated-container disposal problems, and should cost less. Use of this technique may need more advance planning and loss of flexibility for changing chemicals quickly in the field, but errors in chemical selection by semiskilled workers can be eliminated. This technique should be put to the test in an appropriate area.

10. Drag Cleanup - Since the forward speed of the helicopter is limited by power and nosedown attitude, drag cleanup of the aircraft and spray equipment is important. Significant drag reduction and increase in swath speeds have been achieved in agricultural airplanes with turbine engine installations, wing-root fairings, and spray equipment integrated into the lower wing trailing edge of a biplane. Helicopter spray equipment manufacturers are designing lower drag spray equipment which is mounted up under the helicopter.

    The problem of drag of external buckets restricts practical speeds to about 65 mph in most helicopters now used. In future some fairings will probably be applied to permit faster speeds. The use of faired slingers mounted on the bottom of the helicopter offers advantages in low drag, but disadvantages in additional time for internal loading and lower payloads. With buckets the loading time could be reduced substantially by using two buckets, one of which is being loaded while the other is applicating. Another advantage of externally slung buckets is that the load can be dropped in an emergency, such as engine failure. This means that a heavier payload can be carried with safety. Internal load dump is provided, but still takes time, which is critical in the engine-failure case.

8.0 CONCLUDING REMARKS

8.1 Objectives

The objectives of this study were twofold, (1) to establish the potential benefits of the increased use of rotorcraft in agriculture and forestry and (2) to identify the aeronautical technology that must be applied to future rotorcraft designs to maximize applicator efficiency and safety. Measures of efficiency include the increase in productivity of the land and the impact on the unit cost of producing the food stuff and lumber.

The following key questions were addressed in this report:

1. What is the right mix of helicopters and airplanes in agriculture and forestry?

Answer - In agriculture, smaller helicopters (up to about 4,000 pounds gross weight) are displacing smaller airplanes because of better efficiency in small congested fields. Medium size helicopters are being used more in orchard and citrus applicating and are more productive than small helicopters or airplanes. In forestry, medium and large helicopters are being experimented with and a trend toward more helicopters is evident, principally because the helicopter can operate alongside the forests with slinger buckets and with short ferry distances. The overall ratio is predicted to go from about 10 percent of the fleet at present to 20 to 30 percent of the fleet by the year 2000.

2. Is there a need for a special agricultural aerial-application helicopter? What characteristics would it have?

Answer - There is no need for a specialized ag helicopter. The distinct advantages of (1) lower unit costs through higher production rates and (2) maximum utilization to reduce direct operating costs dictates a multiple-use helicopter. The characteristics needed are increased payload, reduced drag (including external spray gear), a much better power match with power reserve, crash safety features, and pilot comfort features.

3. Are turbine-powered helicopters and turbine conversions cost effective?

Answer - Yes, turbine-engine installations have a much better power match, good high/hot performance, and better reliability than reciprocating engines. Combined with other advances the turbine helicopter has a better useful-load-to-gross-weight ratio. Larger operators of turbine helicopters report favorably, but the initial cost still deters many small operators.

4. How can we increase productivity of helicopters most economically?

Answer - Generally, by increasing swath speed, swath width, and payload. This does not hold true for all operations, especially small fields and orchards where small slow helicopters are adequate. However, in competition with airplanes on large fields, high productivity will only be achieved with higher gross weight helicopters which have high speeds, higher payloads, and can use longer spray booms and rotor tip vortices to attain wide swaths. For high-rate application of fertilizers utilizing slingers, high payloads are mandatory for helicopters to be competitive.

5. What is the effect of paylaod/gross weight on productivity?

Answer - Productivity increases with gross weight for all practical sizes of helicopters; however, small field sizes, low application rates, and many obstacles dictate a small more maneuverable helicopter.

6. How can chemical hazards be reduced?

Answer - By closed circuit chemical mixing, handling, and loading; batch mixing; and by pilots and ground crews wearing protective clothing and respirators. Cockpit air filtering or pressurization is also needed.

7. What are future trends and the impact on helicopters of:

- use of granular fertilizers and herbicides in forestry?

Answer - The trend is to use large helicopters with external bucket slingers for this work in forestry, and the market is increasing. More development in slingers and an understanding of the aerodynamics of the granules in the proximity of rotor downwash is needed to attain maximum productivity.

- Use of aerial application for dry fertilizer at high rates in agriculture?

Answer - Development work in forestry will also improve helicopter productivity in agriculture. However, both airplanes and helicopters will have stiff competition from ground application because of economics in most areas. Also the timing of fertilizer application is not as critical and ground application is scheduled to even out farm help workload.

- Use of high-rate application of insecticides on orchards and citrus groves?

Answer - Larger helicopters are needed to agitate all of the foliage for uniform coverage, and the trend is toward more helicopter use because of timeliness of application.

- Seeding by air in agriculture and forestry?

Answer - The trend is more widespread use of seeding by air. The helicopter is the logical choice because of accuracy on all types of terrain, short ferry distances, and good swath width control with external buckets and slingers. Mixing seeds and fertilizer in slinger buckets is being done with good results. Internal hoppers with slingers and venturi spreaders are also being used.

- biological control of insects?

Answer - It is estimated that 50 percent of the insecticides sprayed in the U.S. are wasted. Reasons for this are overspraying, spraying the wrong chemical, indiscriminate spraying, drift, skips, and droplet size variations. Indiscriminate spraying of insecticides destroys biological controls by killing predator and parasite insects, accelerates development of resistant strains of harmful insects and is expensive. There is increasing demand for more biological controls and less use of toxic chemicals that kill both useful and harmful insects. Chemicals also need to be selected more carefully, sprayed accurately, and timed to kill insects most effectively.

The increased accuracy, exact timing, and droplet uniformity requires development of spray booms and misters that will applicate insecticides rapidly, accurately, and with uniform coverage. Helicopters can operate at night, and in low weather minimums, fly slow, and use the rotor downwash to agitate plants bushes and trees. The unique capabilities of the helicopter can be utilized in the distribution of pheromones, sterile insects, and other very selective insect biological controls. Therefore, biological control technology will probably promote new uses for helicopters.

8.2 Benefits in Using Helicopters in Agriculture and Forestry

The benefits in using helicopters in agriculture and forestry have been identified as follows:

(a) Low turn time and turn radius - can slow up and turn as required

(b) Can operate from nurse truck at side of field on unprepared site

(c) Can reload from a platform on top of nurse truck

(d) Can applicate small irregular fields with obstacles and uneven terrain or large fields

(e) Can border the fields and get in corners near obstacles

(f) Can fly at desired speed, low or high, for best efficiency

(g) Can fly in low weather minimums, in fog and at night

(h) Can use rotor downwash to agitate foilage for better distribution and coverage

(i) Can use rotor tip vortices to increase swath width short spray booms

(j) Can use long spray booms and utilize tip vortices to increase swath width

(k) Can lift external loads, slingers, logs, firefighting crews, and equipment

(l) Helicopters are versatile and can do other jobs off-season to increase utilization and reduce costs

(m) Can fly close to tree canopy in mountainous terrain

(n) Can bring in firefighting crews and equipment to remote areas inaccessible by other means

(o) Can operate in close proximity to urban population buildup with low noise and obtrusion

(p) Substantial fuel saving compared to ground application

(q) Substantial manhour saving over ground application

(r) No mechanical contact with plants so diseases are not spread throughout the field

(s) Crops are not damaged, and fields are not compacted

(t) Much faster than ground operation

(u) Increases productive land in otherwise inaccessible areas

(v) Permits double cropping by reseeding before first crop is harvested

(w) Provides an effective means of frost control

8.3 High Payoff Research in Agricultural and Forestry Helicopters

Research needs have been identified in the following areas:

(a) Pilot-error accidents

(b) Wire-strike and obstacle-strike problems

(c) Reciprocating-engine failures

(d) Improved spray booms and spreaders

(e) Automatic flagmen and navigation systems

(f) Night application technique and equipment

(g) Quick conversion from liquid to dry materials

(h) Pilot station requirements in logging operations

(i) Chemical batch mixing and closed-circuit mixing and loading

(j) Drag cleanup of helicopters, spraying equipment, and dry material spreaders

(k) Development of a cost-benefits-analysis model to evaluate helicopter design and operational features and performance capability

(l) Determination of the level of crashworthiness features needed in agricultural helicopters, such as fuel contaminant, fire prevention, energy absorbing landing gear, delethalized cockpits, energy absorbing seats, and improved egress

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APPENDIX A

The following is a translation of Paragraph 1.2.8, Pages 22 through 27, of Reference 13 on agricultural helicopter use in the USSR from "Helicopters, Selection of Optimal Design Parameters", by Tishchenk and Nekrasov, 1976. Translation by W. Z. Stepniewski.

1.2.8 Criterion for Evaluating Operational Effectiveness of Agricultural Helicopters

The use of helicopters in agriculture in the USSR is expanding all the time. While in the beginning, their use was limited to treating vineyards and orchards, helicopters have recently been used extensively in the application of herbicides to the field and for fertilization of winter crops. The application of fertilizing at times considered optimal from the viewpoint of agrotechnology; i.e., in the spring when there is a lot of moisture in the soil and use of surface vehicles is not feasible, results in a considerable increase in the yield.

The experience of the helicopter industry in the USSR and abroad shows that as yet there is no serious need for the development of a special agricultural helicopter. Multipurpose transport helicopters are modified for this work by externally installing additional equipment. This approach does not provide an optimal helicopter for a given type of work, and this appears to be a significant drawback of the established practice. On the other hand, the present approach does have some advantages, primarily associated with the fact that agricultural operations are performed seasonally and consequently, the specialized helicopter would be destined for long down-times with the corresponding problems: how to occupy the crews during idle times, and how to utilize the quite extensive supply of specialized equipment, especially in light of the existing calendar limitations for their applications.

Use of the universal helicopters makes it possible to utilize them in the intervals between agricultural applications for liaison, transport, and other operations. Moreover, the universal helicopters are always produced in larger quantities than specialized rotorcraft and consequently, are cheaper, which is also very important, since the cost per hectare treated determines in considerable measure the advisability of using the helicopter for this type of operation.

The following discussion is equally related to the modified universal helicopter and specialized agricultural helicopters.

When considering agricultural operations, it is very important to accomplish the required scope of work in short calendar periods as dictated by the growing cycle. Therefore, it is very important that expenditures of time associated with servicing the helicopter, preflight preparation, and routine inspections are as small as possible, at least during their seasonal utilization. On the basis of these considerations, it is best to take absolute productivity as the primary criterion for the operating effectiveness of agricultural helicopters, and to use relative productivity as a secondary criterion.

Absolute productivity of agricultural helicopters can be defined as the area in hectares (one hectare = 2.47 acres) treated by the helicopter per hour, while relative productivity is defined as the absolute productivity divided by the gross weight.

When determining productivity in the following considerations, we shall examine the time associated with performing four basic forms of operation which define the operating cycle of agricultural helicopters.

First is the time T_1 expended on dusting or spraying; i.e., operations associated with applying chemicals to fields. This is considered useful time since it is spent in performing functions which are essential to the helicopter mission.

Second is the time T_2 expended by the helicopter on turn-arounds after passing the strip being treated. As a rule, treated fields are represented by parallel strips, one after another.

Third is the time T_3 required for takeoff, acceleration, and flight from the servicing area to the field being worked and return, followed by deceleration and landing.

Fourth is the time T_4 required for supplying the chemicals to the helicopter.

Here, we have not mentioned the time expended on fueling, as we are assuming that this is accomplished with the engines not operating; i.e., with no expenditure of resources while, in contrast, loading of chemicals is performed with the engines running.

On this basis, agricultural helicopter productivity can be defined as the ratio of the area treated to the time expended for actual operation.

$$\Pi_{agr} = S/T = S/(T_1 + T_2 + T_3 + T_4) \tag{1.30}$$

where S is the area treated by a helicopter dispensing a complete load of chemicals (in hectares); T is the time expended (in hours) on loading the helicopter with chemicals, takeoff, and flight to the field being worked; working the field itself, and return for the next servicing; and Π_{agr} is the productivity in ha/hr.

Area S can be expressed as the ratio of the helicopter load including chemicals, G_{ch} (in tons), to the so-called chemical application norm, H, thus giving the quantity of applied chemicals in tons per hectare:

$$S = G_{ch}/H. \tag{1.31}$$

As the helicopter traverses the field it treats a strip of length L_p, usually termed a pass. The overall length L_Σ of the strips treated by the helicopter per servicing is

$$L_\Sigma = 10S/B \tag{1.32}$$

where L_Σ is the overall length in km; B is the width of the treated strip, or swath width in meters.

It is obvious that the number of passes over the field per servicing is

$$n = L_\Sigma/L_p. \tag{1.33}$$

Having these relationships, we can obtain expressions for the components of operating time T.

Time T_1 in hours spent applying the chemicals can be expressed in the following form:

$$T_1 = L_\Sigma/V = 10S/VB = 10G_{ch}/VHB. \tag{1.34}$$

At first glance, one could come to an unexpected conclusion that productivity of agricultural helicopters, calculated only on the basis of time T_1, is independent of the chemical load G_{ch} and the application norm H. Indeed, by substituting the above expression for T_1 into Eq (1.30), and assuming that $T_2 = T_3 = T_4 = 0$, then

$$\Pi_{agr} = 0.1\ VB. \tag{1.35}$$

In determining T_2—the time spent on turns—we shall assume that after passing the strip, the helicopter performs a turn with a bank angle of 45° without reducing its speed. This means that the load factor is $n = 1.41$. In this case, the centripetal force is equal to the weight, while the time for a complete turn in hours is

$$T_2 = (1/3.6)(1/3600)(2\pi/9)V(L_\Sigma/L_p) = 0.494 \cdot 10^{-3}(SV/BL_p) = 0.494 \cdot 10^{-3}(G_{ch}V)/HBL_p. \tag{1.36}$$

The time spent in flight from the service area to the field and back can be defined as

$$T_3 = 2L_{fi}/V_{ft} \tag{1.37}$$

where L_{fi} is the distance in km from the service area to the field; V_{ft} is the average flight speed in km/hr, determined taking into account the time lost in hovering, acceleration, and deceleration.

For simplicity, we shall assume that $V_{ft} = \frac{1}{2}V$.

Finally, the time lost in loading the chemicals is determined by the amount of material loaded and the productivity of the loading mechanism:

$$T_4 = G_{ch}/\Pi_3 \tag{1.38}$$

where Π_3 is the productivity of the loaders in tons/hr.

Substituting Eqs (1.34), (1.36), (1.37), and (1.38) into Eq (1.30), and making simple transformations, we obtain the following expression for productivity of the agricultural helicopter:

$$\Pi_{agr} = 1/[(10/VB) + 0.49 \cdot 10^{-4}(V/BL_p) + (14L_{fi}/VG_{ch}) + (H/\Pi_3)] . \tag{1.39}$$

The relative productivity of the agricultural helicopter is obtained as the ratio of Π_{agr} and the gross weight, G_{gr}:

$$\overline{\Pi}_{agr} = \Pi_{agr}/G_{gr} . \tag{1.40}$$

It is possible to take the individual quantities appearing in Eq (1.39) and evaluate their influence on productivity. Increasing the flight speed leads to a reduction in the time expended on chemical application and on ferrying from the loading area to the field and therefore, the productivity increases. On the other hand, increasing the flight speed also increases the time expended on turns, resulting in decreased productivity. Calculations show that the optimal velocity from the viewpoint of productivity is higher than the usual helicopter speed and therefore, an increase in speed improves productivity.

Further, the wider the swath width B, the higher the productivity. The total productivity also becomes higher with an increase in the pass length L_p, weight G_{ch} of the chemicals, and productivity Π_3 of ground-based loaders.

Productivity decreases with an increase of the chemical norm H and the distance (L_{fi}) from the loading area to the field.

The results of calculations based on Eqs (1.39) and (1.40) are shown in Fig 1.8. In these calculations, the helicopter gross (takeoff) weight varied from 1 to 20 tons. The pass length was assumed to be L_p = 1 km. Ferry distance from the base was 3 km, and fertilizer application norm was 0.3 ton/ha. Speeds were taken as 120, 130, 150, 170, and 200 km/h respectively, for weights of 1, 2, 6, 12, and 20 tons. Productivity of agricultural helicopters, Π_{agr}, as calculated from Eq (1.39) is shown in Fig 1.8a for the above-indicated weights and speeds; using three values of the swath width (B = 20, 30, and 40m), and with the assumption that the loader productivity Π_3 = 50 ton/h. Fig 1.8 shows the relative productivity for B = 40 meters. It can be seen from Figs 1.8a and 1.8b that absolute productivity steadily increases with gross weight, while the relative productivity has a maximum gross weight of about 4 tons.

If, with an increase of the gross weight, we assume that the width of the swath and ground loader productivity also increase in such a way that the following values of B; B = 14, 16, 25, 40, and 59m; and Π_3 = 25, 50, 150, 300, and 500 ton/h correspond to the previously indicated gross weights, then the absolute productivity of agricultural helicopters

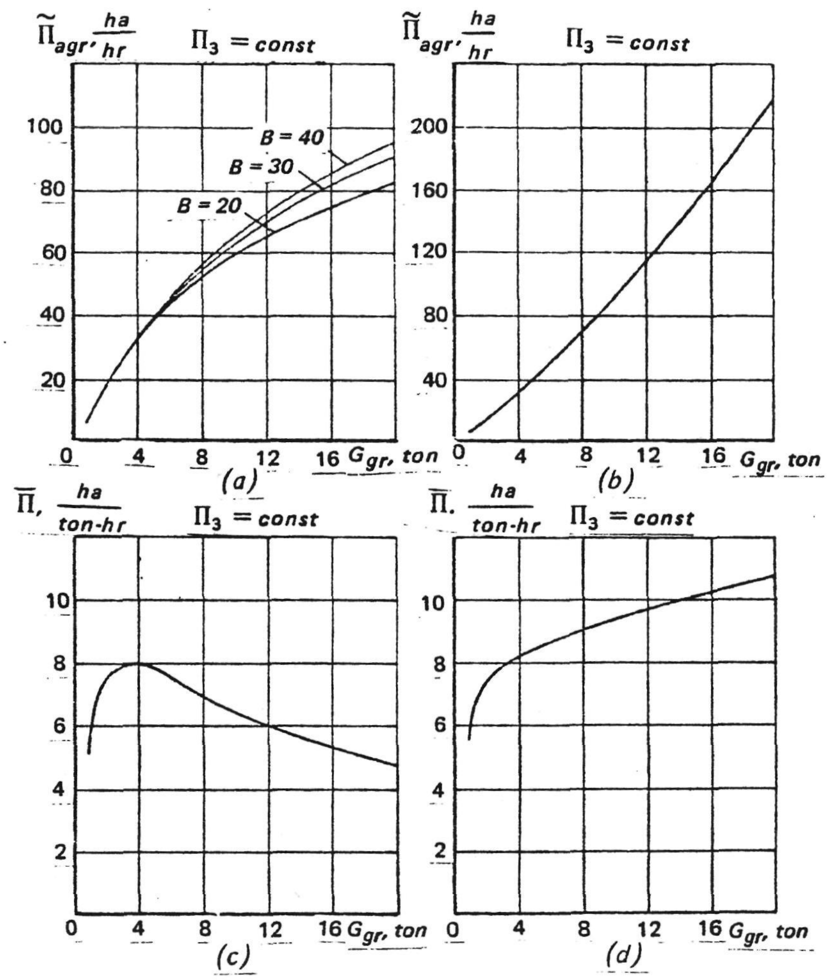

Figure 1.8 Influence of gross weight on absolute and relative productivity of agricultural helicopters

increases with an increase in G_{agr} as shown in Fig 1.8c. In this case, the relative productivity $\overline{\Pi}_{agr}$ (Fig 1.8d) also increases with an increase in the gross weight. However, for gross weights higher than four tons, the rate of increase in relative productivity diminishes.

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APPENDIX B

List of Operators and Agencies

The following list of operators and others concerned with the agriculture and forestry industry were contacted by telephone and in many cases visited. Their helpful comments, useful data, and opinions on needs in making aerial application more productive and cost competitive are gratefully acknowledged. Hopefully this report will be of use to the operators in solving todays problems, as well as identifying research and development needs for the future.

Aerial Patrols Box 2106 N. Canton, OH 44720	Terry Ewing, President
Ag-Rotors, Inc. P. O. Box 578 Gettysburg, PA. 17325	Dr. Carrol M. Voss, Pres Richard H. Sawyer, Admin. Henry J. Whitfield, Director of Ag Ops
Air Services International 15000 N. Airport Drive Scottsdale, AZ 85260	Jim Burrell, Vice President
Allied Helicopter Box 6216 1201 W. 36th St., North Tulsa, OK 74106	Roy B. David Ed McGee
AVAG, Inc. P. O. Box 156 Richvale, CA 95974	Gerry Compton, Owner
Aviation Education Programs FAA 800 Independence Ave., S.W. Washington, D.C. 20591	Mervin K. Strickler Chief, Avn Ed Programs Division
Basham Flying Service Madison, AL	Frank Basham, Owner
Bell Helicopters (Textron) P.o. Box 482 Ft. Worth, TX 76101	Harold E. Lamont, Engineering
Coastal Ag-Chem P. O. Box 1307 1015 E. Wooley Rd. Oxnard, CA 93030	Earl Griffin, Manager
Columbia Helicopters, Inc. P. O. Box 3500 Portland, OR 97208	Jack Pyle, Dir of Maintenance George Pittle Kau, Chief Inspector Myron R. Lamont, Command Pilot

Conair Aviation Ltd. Box 220 Abottsford, B.C. Canada V25 4N9	Nick Perkins, Engineering
Condor Helicopters P. O. Box 3356 Ventura, CA 93003	Stuart Taft, Chief Pilot Dave Morua, Pilot
Del Norte Technology P. O. Box 696 Euless, TX 76039	Harry Mitchell, Product Mgr Airborne Systems
Econ Inc. 900 State Rd. Princeton, N.J. 08540	George Hazelrigg, Jr. Director, Systems Engineering
EPA TS770 401 M. St., S.W. Washington, D.C. 20420	Phil Gray Office of Pesticides Program
Fetsco Aviation Sales & Transportation P.O. Box 61 Media, PA 19063	John J. Fetsco, President
Gila River Industries, Inc. 4010 S. 59th Avenue Pheonix, AZ 85009	Bill Hall, President
Golden Harvest Helicopters P. O. Box 262 Wingate, IN 47994	Jerry Babcock, Owner
Helicopter Assn. of America 1156 15th St. N.W. Suite 610 Washington, DC 20005	Ed Hutcheson, Helicopter Safety
Helitec Corp. 4930 E. Falcon Drive Mesa, AZ 85205	J. E. Boyles, Manager Jim Jeffries, Operations
Johnson Aerial Applicators 42400 S.E. Oral Hull Rd Sandy, OR 97055	John Johnson, Owner
Kearney Air Service 4215 Avenue F P. O. Box 1773 Kearney, NB 68847	Don Streeter, Senior Pilot Connie Streeter, Ag Consultant

Marsh Aviation East Falcon Drive Mesa, AZ 85205	Floyd Stillwell, President
NASA Langley Research Center Hampton, VA 23665	Dr. Bruce Holmes Dal V. Maddalon
National Agricultural Aviation Assn. National Press Building Suite 459 Washington, DC 20045	Harold M. Collins Farrell Higbee
National Helicopter Service & Engineering 16800 Roscoe Blvd. Van Nuys, CA 91406	Richard Hart, President
Omniflight Helicopters, Inc. Rt. No. 7, Highway 51 South Janesvice, WI 53545	Richard Werling, President
Orlando Helicopter Airways P. O. Box 2802 Orlando, FL 32802	Fred P. Clark, President
Precision Helicopters Box 177 Willard, OH 44890	Bob Chase
Rotor-Aire, Inc. 3302 N. Stoughton Rd. Madison, WI 53704	Ed Morgan, Vice President
Shirbill Airways 8095 State Route 44 Ravenna, OH 44266	Tim Gaunt
Soil Serv, Inc. 1427 Abbott Street Saginas, CA 93901	Jack C. Bolton, Ops Mgr Ron Long, Chief Pilot

Soloy Conversions, Ltd. P. O. Box 60 Chehalis, WA 98532	Joe Soloy, President
Strong Steel Ag-GSE/Trucks P. O. Box AK Ventura, CA 93001	Edgar M. Boynton (P.C.A.)
U. S. Forest Service Fort Missoula Missoula, MT	Robert Ekblad, Equipment Development Engineering

APPENDIX C

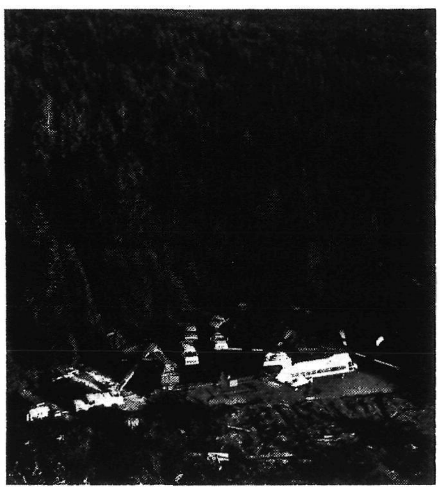
The following article about the use of large helicopters in forestry was published in the April 1977 issue of Agrichemical Age. It is reprinted here by permission.

Giant Helicopter Has Future In Large Acreages

Speedy loading of big payloads characterizes this fertilizer application system.

New mechanical developments coupled with a helicopter that moves fast and distributes fertilizer quickly over large areas, may provide a key to future fertilization of large acreages of such crops as wheat, potatoes, corn, rice and grazing land.

The helicopter, with the aid of its support equipment, spread 2,186 tons of nitrogen fertilizer on 9,800 acres of Douglas fir forest near Portland, Oregon recently. The woodland received 6,500 pounds of fertilizer in each 75-second sweep of the Boeing Vertol 107 flown by Columbia Helicopters of Aurora.



LEFT: A high-capacity helicopter coupled with a high-speed conveyor system increase the speed and efficiency with which fertilizer is applied to large tracts of land—in this case, a managed Oregon forest.
ABOVE: Developed by Columbia Helicopters, Aurora, Oregon, a conveyor system rapidly moves fertilizer into a loading hopper in preparation for filling the helicopter for its next run.
RIGHT: The Boeing Kawasaki Vertol 197 makes a swath run over Crown Zellerbach's managed forest. Each 75-second sweep of the helicopter applies 6,500 pounds of fertilizer.
BELOW: Filled with over three tons of urea fertilizer, which is loaded in less than a minute, a helicopter takes off for a swath run.

Ralph Duddles, supervisor of forest practices for Crown Zellerbach, owner of the managed forest, said the new method achieved pinpoint accuracy and uniform coverage, using a helicopter with increased production capability and a patented spreader device mounted on the helicopter's underside. The Vertol evenly spread within 6 pounds of the company's required 440 pounds per acre.

The rate of application, 40-50 tons per hour, was faster than any Duddles' company has encountered in four years of fertilizing operations. "In 16 days, of which they flew 14, Columbia spread an average of 150 tons a day," says Bob Cadwallader, reforestation forester for the Veronia managed forest. "In the past, other companies who have worked with us were limited to 50-60 tons a day," he adds.

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GIANT HELICOPTER

Continued from page 24

The 10,000-pound Vertol's unique twin rotor system will lift its own weight plus 1,500 pounds—and the spreader mechanism. This device, invented by Columbia Helicopters, has more than doubled the width of a single spread of the fertilizer, while at the same time eliminating the spotty coverage of other methods.

The fertilizer was hauled in bulk by K-line trucks pulling two tank-trailers with 34,000 pounds per tank. From the bottom of a tank trailer, the fertilizer flows onto a conveyor belt which moves 30,000 pounds into a hopper atop the truck bed. This hopper and conveyor system automatically measures 6,500 pounds into a second, load hopper.

When the helicopter lands, a long conveyor is immediately inserted into the rear of the helicopter. Once tiny feelers at the tip of the conveyor feel contact within the helicopter, an automatic guidance system takes control from the operator and nudges it into the internal bin. Immediately, the conveyor transfers the measured fertilizer into the bin. In seconds, vibrators within the load hopper shake the last 2,000 pounds onto the conveyor and audible signals warn the pilot to prepare for takeoff. The helicopter is also refueled as necessary—fueling takes five seconds.

Total time on the ground is 55 seconds.

Once above the target area, the pilot hits a switch and 6,500 pounds of fertilizer is evenly distributed over the forest in a 200-foot wide swath at 86 pounds per second. Calibration of the spreader mechanism will allow different application rates. □

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