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SYSTEM DESIGN REQUIREMENTS FOR ADVANCED ROTARY-WING AGRICULTURAL AIRCRAFT

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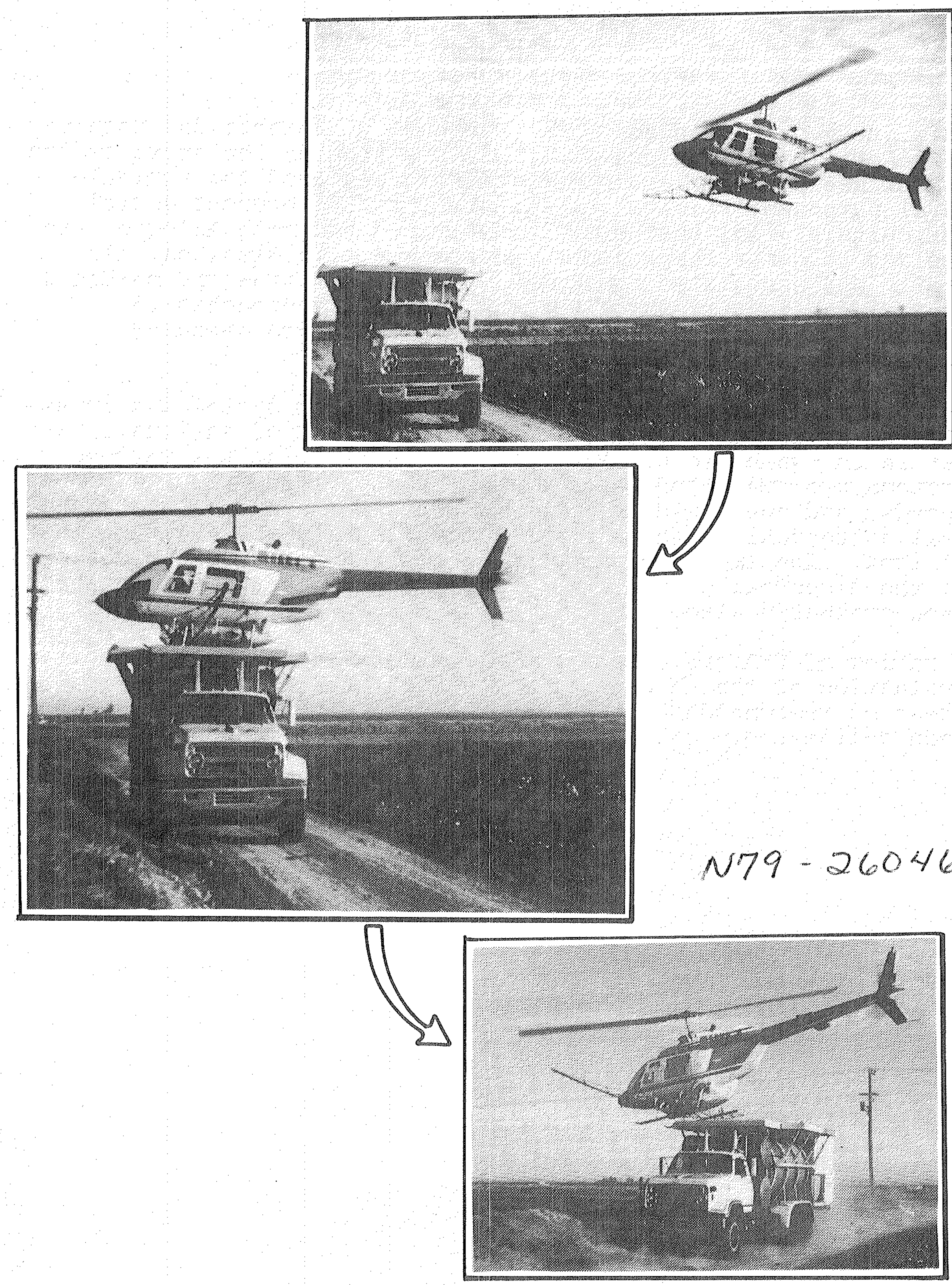

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Frontispiece: BHT Model 206 during operations.

SUMMARY

This study on "Advanced System Design Requirements for Rotary-Wing Aerial Applications Systems" investigates the state of the art of helicopters, equipment, and systems used for agricultural purposes. Limitations inherent to the present aerial agricultural (Ag) business are evaluated and methodologies are evolved to generate projected improvements in missions, aircraft, and associated equipment (ground, airborne and marking). Typical configurations of various possible approaches to designs for Ag aircraft are included; these are based on criteria derived in this study.

Various possible methods for improving the Ag system are investigated by computer analysis as is the effect of various parameters on swath width. Productivity indices for the various systems are evaluated based on costing, payloads, cruise speeds, and swath widths. Hourly costs to operate a system as well as to achieve three typical missions are reviewed for the designs. The impact on mission accomplishment by optimization of the dispersal system, the aircraft, and other equipment has been evaluated also.

A review of FAA and other regulations has been made to permit evaluation of the effects of removal or changes of the same. Areas of recommended future research and development have also been delineated.

PREFACE

This study, particularly the portion which reviews the state of the art of the aerial application of agricultural materials, owes much to the persistent efforts of both fixed and rotary-wing aircraft pioneers. These operators, engineers, pilots, and ground personnel have demonstrated a tenacity of purpose and great ingenuity to survive in a most difficult business, resulting in benefit to the farmer, the agrotechnology business, and the nation. Discussions with such personnel have been most illuminating in reviewing past efforts, determining current modes of operation, and in projecting future trends in missions and requirements. Personnel from the Helicopter Association of America (HAA), the National Agricultural Aviation Association (NAAA), cognizant helicopter producers, and various equipment manufacturers have been most generous in donating their time and efforts in the furtherance of this study.

Many BHT personnel have contributed both directly and indirectly - namely: Mr. Ray Ingham, Commercial Marketing; Mr. F. Cantwell, Project Management; and Mr. Joe Mashman, Vice President Special Products. Technical contributions by Messrs. H. Upton, Lee Erb, D. Crist, R. Bennett (Ph.D.), Bharat Gupta (Ph.D.), F. Krystinik and J. Brunken have been most helpful.

Additionally, the guidance and encouragement of Dr. Bruce J. Holmes of NASA-Langley Research Center in conducting this study has been most appreciated. Previous NASA (NACA) work forms a strong base upon which to build the needed aircraft/equipment/ground support technology for improving the production of food in the world.

TABLE OF CONTENTS

TABLE OF CONTENTS (Concluded)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Concluded)

LIST OF TABLES

LIST OF TABLES (Concluded)

1. INTRODUCTION

The significance of improving agricultural methods by the use of more efficient aircraft aerial application systems cannot be overemphasized in view of the constantly expanding world population. Presently, about 1400 helicopters are estimated to be employed in agricultural work in the U.S.A; these treat about 20 percent of the aerial agricultural acreage and comprise 10 percent of the total Ag fleet (reference Table 1).

TABLE 1. GENERAL AIRCRAFT/AG DATA

<u>National Business Aircraft Association Source Data (NBAA)</u>

1976 Year

- 1/3 of Commercial Helicopters are Ag Use
- 1/10 of Commercial Helicopters are Ag Specials
- 1/10 of Ag Aircraft are Helicopters
- 2/10 of Total Aircraft Treated Areas is by Helicopter
- Average Ag Flight Time/Helicopter is 292 hr/yr

<u>Number of Ag Involved Helicopters - Domestic</u>

	1976	1977
NBAA	643	--
Helicopter Association of America	937	--
BHT Marketing Estimate		1400

<u>Total Estimated World-Wide</u>

- No. of Ag Aircraft = 21,000
- 1/10 Estimated to be Helicopters = 2100 Units

The diverse uses for Ag helicopters (**Figure 1**) coupled with economic realities have required kit modification of existing aircraft that are produced for general utility purposes. This has limited the practical development of single use aerial farm helicopters (designated as "specials" herein), with system effectivity suffering in that multipurpose vehicles have design compromises reflecting a reduced capability.

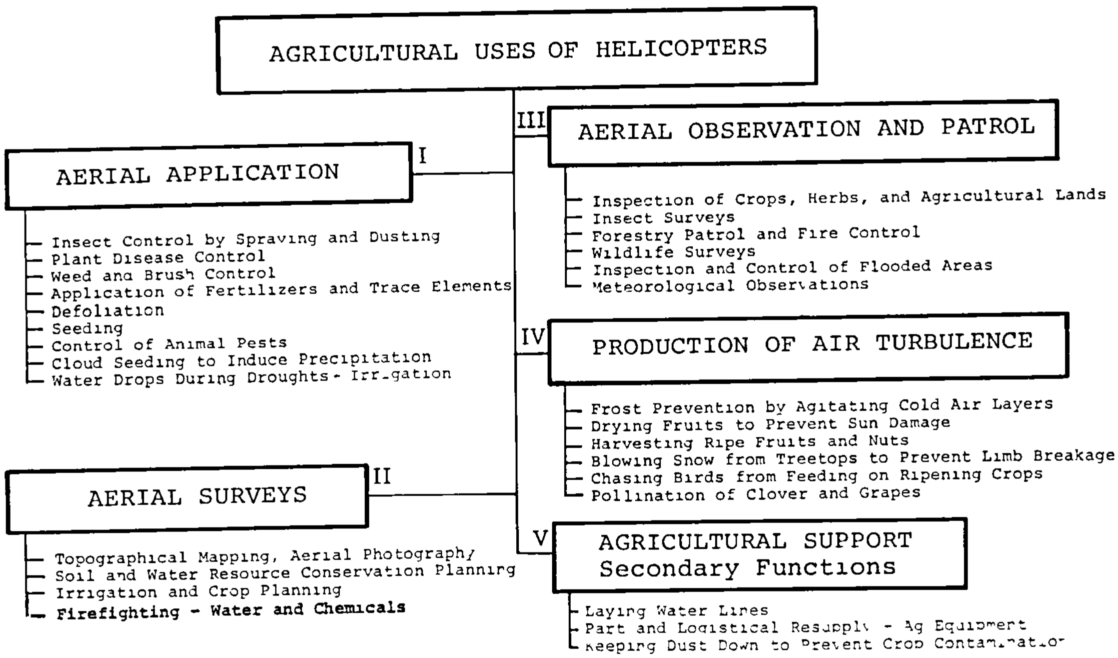

Figure 1. Agricultural uses of helicopters.

Pioneering aspects of Ag aircraft operation (each job facing different problems) have also tended to limit technical progress. Accident rates with Ag fixed wings are high (25 accidents, 2.3 fatalities/100,000 flight hours); operational, financial, and material-handling risks have also kept costs up. Most Ag aircraft have been powered by reciprocating engines, with the fixed wing enjoying slight advantages in lift and speed capability over the helicopter (airplane disposable load-to-gross-weight ratio = .40 versus .35 for that of the helicopter). The turbine-powered helicopter has disposable load-to-gross-weight ratios exceeding .50 (better than some new turbine-powered airplanes). Also, the increased cost of turbine-powered airplanes has reduced the delta between airplane/helicopter prices. The more efficient duty cycle of the helicopter has additionally increased penetration of the agricultural market.

NASA has previously encouraged the examination of pertinent factors of both fixed and rotary-wing aircraft systems as used for the aerial application of agricultural materials through the establishment of various workshops, symposiums, and contractor reports as per References 1, 2, 3, and 4.

A poll of operators and their opinions on the relative factors important for Ag aerial operations was reported in Reference 2. These data have been utilized in generating Table 2 with the elimination of some elements not germane to helicopter use, and by establishing the operator-stated most important item (drift) as unity for the fixed-wing and crash survivability as that for the helicopter.

Table 3 indicates the Ag helicopter accident rates as generated by the NAAA on FAA preliminary 1977 data. It appears that the concern of the helicopter operators for propulsion reliability (.70 rating) is borne out by the 20 percent number of accidents attributed to the engine failure rate. The 48 percent of accidents caused by wire and obstacle strikes apparently does not appear directly as a problem to these helicopter operators. However, problem number 4 (Table 2 Cockpit Area Suvivability) and problem number 13 (Obstacle Detection and Avoidance) could be assumed to indicate helicopter operator concern in this area. Perhaps for fixed-wing operators this unconcern with obstacle strikes (.445 rating) is related to the general human tendency to ignore unpleasant statistics, i.e., 50,000-plus traffic deaths per year from automotive travel. It may also be noted that the helicopter potential of being able to autorotate in the event of engine stoppage, from almost any low level flight condition that involves significant forward motion, tends to remove concern over such failure.

The objectives of the subject study, analysis, and design work are the following:

- To evaluate the state of the art, particularly in aircraft design, as applicable to agricultural helicopters. Data on Ag aerial dispersal system equipment are included.

- To identify topics and areas requiring more research. Biological or agronomic topics are not considered except when potential markets influence aircraft design and operations.

- To evaluate regulatory and certification requirements as applicable to design and operations, and recommend changes, if deemed desirable or necessary.

TABLE 2. FACTORS IN AG AERIAL APPLICATIONS

Aircraft Aviation User Requirement Priorities

	Problems	Rating fixed wing/helicopter combined response	Helicopter response
1.	Drift	1.00	.90
2.	Propulsion Reliability	.965	.70
3.	Pilot Protection from Toxic Substances	.82	.82
4.	Cockpit Area Crash Survivability	.759	1.00
5.	Fire Prevention	.669	.68
6.	TBO Times	.669	.64
7.	Uniform Dispersal Pattern	.635	.62
8.	Protection of Ground Crew from Toxic Materials	.575	.80
9.	Cockpit Comfort	.545	.60
10.	Determination of Uniformity of Coverage During Flight	.50	.52
11.	Accumulation of Dust and Chemicals on Windshield	.455	.62
12.	Ground Handling of Payload	.455	.59
13.	Ground Obstacle Detection and Avoidance	.455	.80
14.	Cockpit Unobstructed View	.455	.30
15.	Swath Guidance	.41	.31
16.	Flexibility of Aircraft to Meet Different Ag requirements	.41	.55

TABLE 2. (Concluded)

	Problems	Rating fixed wing/helicopter combined response	Helicopter response
16.	Controls Location & Design	.41	.55
17.	Noise (External A/C)	.394	.40
18.	Corrosion Inspection & Control	.394	.62
19.	Fuel Consumption	.378	.39
20.	Adjusting Dispersal System to Meet New Application Requirements	.378	.52
21.	"In-the-field" A/C Service & Repair	.364	.45
22.	Monitoring Flow Rate	.364	.45
23.	Effects of Varying Ground Speed or Dispersal	.364	.75
24.	Confirming Uniformity and Concentration of Coverage Post Flight	.348	.50
25.	Change-over Detoxification	.348	.46
26.	Flushout of Dispersal System	.318	.25
27.	In-the-field Repair and Service of Dispersal Systems	.304	.46
28.	Monitoring of Individual Nozzle/Gates in Flight	.304	.47
29.	Washdown of Aircraft	.288	.40
30.	Maintaining A/C Control during Dump	.257	.36
31.	Selecting Dispenser Turn/Off Points	.243	.38
32.	Mid Air Collisions	.243	.40

TABLE 3. 1977 AG HELICOPTER ACCIDENTS* - SAFETY DISCUSSION

Accident	Bell	Brantley	Continental Copters	Hiller	Hughes	Totals
Collision	5	-	-	2	5	12
Loss of Power (Engine)	2	1	1	1	-	5
Total Accidents	11	1	1	4	8	25

% Collision = $\frac{12}{25}$ = 48%

% Engine Failure = $\frac{5}{25}$ = 20%

*NAAA Source

- To propose and illustrate design configurations. Such designs are used to illustrate points tabulated under 1, 2, and 3 above.

The results of this design and analysis study are expected to be used to plan a NASA aerial applications research program and to delineate areas of emphasis for NASA research for future and more detailed system design studies. It may be noted that computations in this study were performed in English units with data conversions made to the Metric system, as applicable.

2. BACKGROUND OF STUDY

2.1 INTRODUCTION

In performing a study of this type, certain assumptions and methods of approach are needed to permit the most effective use of time. Evaluation of the state of the art of aerial dispersal of materials (solids, liquids, slurries) involves examination of many sources of information such as:

- NASA (NACA) reports, memorandums, tech notes, etc.
- Other Government Agency reports
- Discussions and contact with cognizant personnel such as Ag helicopter manufacturers, pilots, operators, the Helicopter Association of America (HAA), and the National Agricultural Aircraft Association (NAAA)
- Review of foreign reports
- Review of aircraft and available dispersal equipment including ground and support items
- Review of literature from:
    - Aircraft manufacturers
    - Equipment manufacturers
    - Periodicals
    - Aircraft books
- Discussions with farmers and farm managers

As the above technique develops a large number of items whose detailed accuracy or source may be difficult to authenticate, approaches to avoid giving misinformation or biased results were needed. This requirement has been achieved by presenting the data gathered from the various sources in tabular form (Appendix A) with general envelope curves drawn from these data to present blanket trends, scope of parameters, etc. It is considered that these envelope curves delineate the state of the art even though aircraft and equipment at particular gross weights possibly do not exist.

The state of the art in the U.S. in piston-powered agricultural helicopters is represented by the BHT Model 47, and its derivatives in that these outnumber others by a large factor (ten to one). For turbine-powered helicopters, the BHT Model 206B has a three-to-one edge over its closest rival. Operations of ultralarge or ultralight agricultural helicopters constitute such a small portion of the market as to be considered negligible. Therefore, in setting up the typical missions of the program, these extremes in sizes were avoided.

Because a broad background of information exists in agricultural aircraft and many significant parameters have been evaluated, a review of various assumptions, approaches, and conclusions for establishing the work priority of this study effort has been made. One highly significant factor in the cost of operation of an aircraft is the number of hours flown per year.

2.2 ESTIMATE OF FLIGHT HOURS

The estimate of the number of agricultural flight hours per year per helicopter is based on the information in Table 4. The following is deduced from this information:

- The average flight time of all rotary wing aircraft in 1976 was about 600 hours.

- About one-half of this time was used for aerial application of Ag materials.

- Most of these aircraft are of dual purpose use (general aviation and Ag) and may be assumed to operate at a yearly rate of 600 hours/year in estimating the per hourly cost of operation.

- Operator discussions of the "Ag Specials" indicate the following:

  - Six Months Growing Season - 3 hr/day 5-day week
    Hr = (3)(5)(26)
    = 390 hr/yr

  - Twelve Months Growing Season
    Hr = 780 hr/yr

For study comparison purposes, the Ag specials are considered to operate a number of hours in Ag aerial applications equal to the total of the utility types, i.e., 600 hour/year.

2.3 PREVIOUSLY ESTABLISHED FACTORS

Other factors established by previous studies may be noted in the following Table 5.

TABLE 4. NUMBER OF HOURS OPERATED/YEAR*

General Helicopters

	Hours Flown	Total Aircraft	Hr/Yr
Rotary Piston			
1974	93,000	786	118
1975	119,000	750	158.67
1976	88,000	657	133.9
Rotary Turbine			
1974	92,000	347	265
1975	114,000	475	206.9
1976	416,000	975	426
All Rotary Wing			
1974	185,000	1,000	184
1975	233,000	1,126	206.9
1976	1,019,000	1,762	578

Aerial Application

	Hours Flown	Rotary A/C Used	
Rotary Wing			
1974	118,000	555	212.6
1976	187,000	643	290

*From "NBAA Business Flying", 1977, Sec 3

NOTE: HAA list for 1976 gives 937 aircraft involved in agriculture and these numbers are used in the tables of Appendix A.

TABLE 5. ESTABLISHED FACTORS

Parameter	Comment
Ferrying speed	Significant for fixed wing aircraft but not so important for rotary wing. Helicopter cruise speeds (80% V_{max}) are considered a reasonable assumed value.
Ferry distance	Important for fixed wing but secondary for helicopters. Farmers need roads for harvesting; therefore, truck/helicopter access is relatively easy.
Swath width	Section 2.4.2.2. Swath tends to be limited by airplane wing span. Helicopter swaths of up to 200 feet-plus widths are possible.
Turning time	Airplane = 30 to 45 sec Helicopter = 12 sec Reduction of helicopter turn time to 7 sec improves productivity 7 - 8% but at the expense of load factor (Reference 5).
Field speed	Determined by needs of required penetration, etc. Frequently, solid fertilizers may be dispersed at cruise speeds.
Field run length	See Section 4
Wind speed	Up to 12 mph crosswind - Higher speeds generate problems with fines. Reference Section 4.0.
Application rate	See Section 8.1
Application efficiency	See Section 8.1
Aircraft load	Appendix A
Loading and service time	1 - 2 minutes quite common
Trailer vs flying helicopter	Cost difference negligible

2.4 ESTABLISHMENT OF STANDARDS

2.4.1 Introduction

In determining the basic state of the art, an establishment of standards for comparison is required. Normally, agricultural aircraft systems are judged by cost/hectare (cost/acre) and the hectares/hours (acres/hours) treated. The Ag aerial application system may be functionally divided as shown in Figure 2. There are three elements as follows:

- ELEMENT I. This is the aircraft which acts as a transport vehicle (pilot, flagman, dispensed material, etc.). For a Remotely-Piloted-Vehicle (RPV) system, the flagman and pilot function could be performed by one person.

- ELEMENT II. This is the ground handling equipment which serves to logistically support the aircraft, its occupant(s), the supply, loading, and mixing of to-be-dispensed material as required. In addition, logistical support of both itself and air equipment is necessary (maintenance and resupply).

- ELEMENT III. The function of the air-handling equipment is to control the aircraft during its dispensing cycle (pilot, semiautomatic or automatic such as computer or manually controlled RPV), and also to control dispensed material (on-off, width of swath, spray generation, density of application, overlap, drift corrections, flow rates, and other factors). In addition, the transfer of materials from aircraft storage hoppers to dispersal points (nozzles, spreaders, dump equipment, etc.) and the actual spraying or spreading apparatus must be made.

2.4.2 Comparison Standards

Standards for comparison purposes were set up in the following manner.

2.4.2.1 Dispensing Velocities

- Spraying. Investigation of vehicle velocities for spraying liquids indicates that the type of the crop, its desired spray penetration, the purpose and nature of the dispersed substance, the rotor downwash value, and the strength of the rotor tip vortices define the desirable speed, i.e., a helicopter may have the capacity to fly faster and cover an area quicker than is actually best for the crop treatment. High downwash velocities may create problems with delicate crops (such as lettuce). The

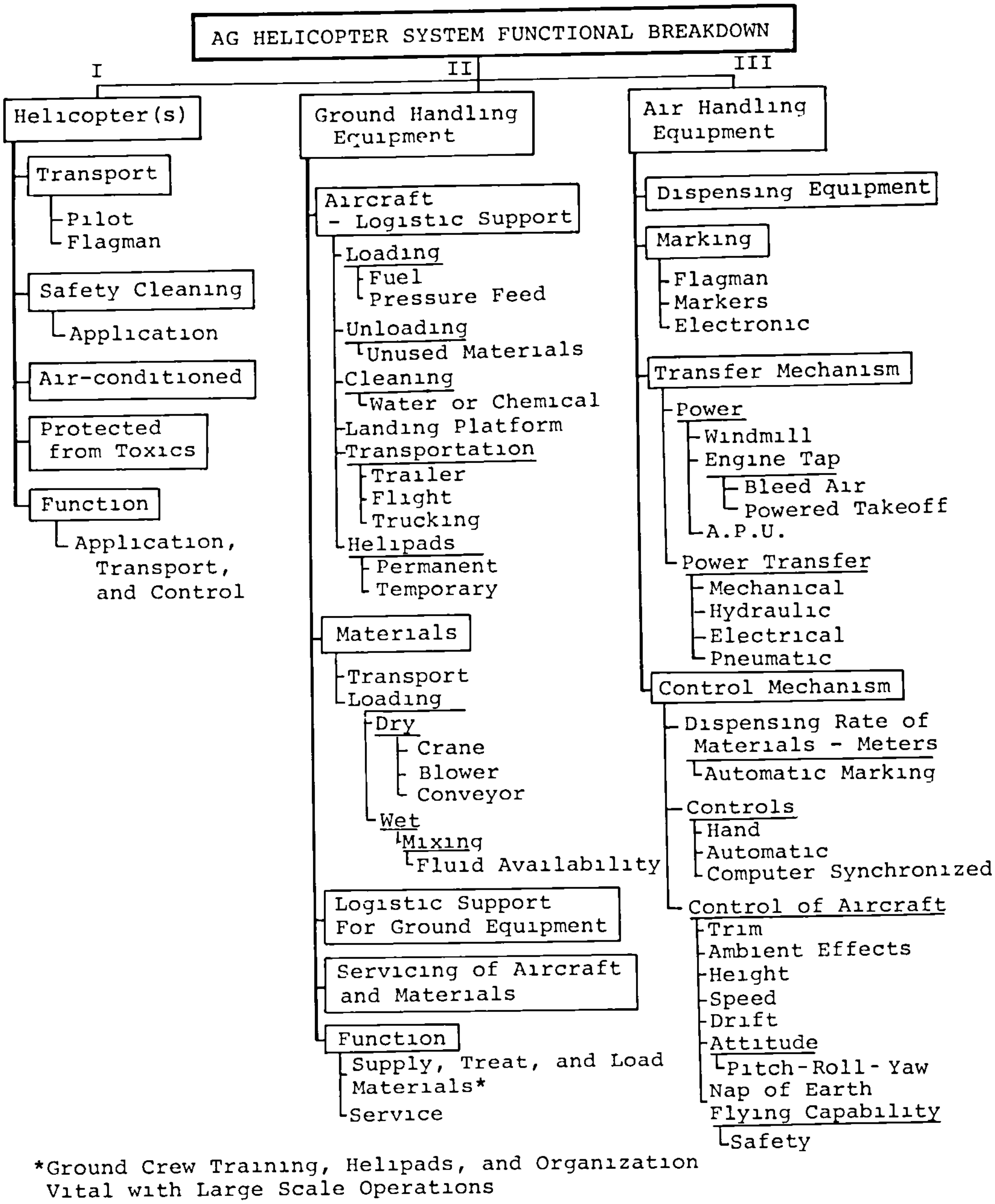

Figure 2. Ag helicopter system functional breakdown.

quality of the treatment (difficult to assess in practice), therefore, is most significant. Productivity criteria for spraying speed selection are shown in Table 6. Although these speeds may exceed practical crop requirements for a particular aerial application, they are used for initial comparison purposes in establishing the state-of-the-art evaluation.

- Solids Dispersal. Velocities for solids dispersal may exceed liquid spraying velocities in that the dispersed materials are relatively insensitive to velocity effects, and crop coverage of fertilizer (common solid) is not sensitive to penetration but rather to uniform dispersal. Therefore, speeds up to V_{cruise} of the vehicle are practical for solid dispersal. Swath width limitations tend to exist due to the power required to disperse the solid material.

2.4.2.2. Swath Widths - Establishment of Swath Factor.

Swath widths may vary considerably depending upon the materials being dispersed (liquid, solid, others), height of the boom, height of the rotor, flight speed, aircraft disk loading, size of the rotor, size of the particle, wind conditions, etc. For some solids with high-powered centrifugal slingers, swath widths of 200 feet are possible. For spray swaths, the width partially depends upon particle size, i.e., for 50-micron diameter or less particle settling may take an extremely long time, or they may never settle depending upon wind, evaporation, and material carrier conditions. Computer studies conducted for a variety of operating conditions by BHT Programs AAM01 and AAM02 gave the results shown in Figures 3 through 15 as follows:

Figure 3 shows the effect of crosswind velocity on the swath width for various helicopter disk loadings and forward flight speeds for a spray composed of 150μ-diameter particles using a 60 foot boom length. At a 10 mph crosswind velocity, a swath width over three times the basic boom span is available.

Figures 4 and 5 show the effects on swath width of varying droplet sizes. It appears that once the minimum size (50μ diameter or less) is exceeded, the particle size has a relatively small influence on the swath width.

Figures 6, 7, and 8 indicate that for either a 5-foot or a constant 10-foot boom height, the position of the rotor has a relatively modest effect on swath width (+50 percent increase).

TABLE 6. PRODUCTIVITY TABLE CRITERIA

Spraying

Condition:

1S. V_{cruise} = Normal helicopter = 80% V_{max}

2S. For internal tanks spray boom $V_{working}$ = 10% Delta V_{cruise} penalty

3S. For external close-fitting tanks and spray boom $V_{working}$ = 15% Delta V_{cruise} penalty

4S. For slung load with boom $V_{working}$ = -20% Delta V_{cruise} penalty

Solids Dispersal

1H. V_{cruise} = Normal helicopter = 80% V_{max}

2H. For internal tanks - exterior spreader $V_{working}$ = -5% Delta V_{cruise} penalty

3H. For external close-fitting tanks $V_{working}$ = 10% Delta V_{cruise} penalty

4H. For slung load with spreader $V_{working}$ = -15% Delta V_{cruise} penalty

NOTE: Power for dispersal is between 7 to 55 horsepower and in some cases involves APU's mounted on the slung load. These horsepower losses are factored into the study when significant values detract from the aircraft engine horsepower available for flight.

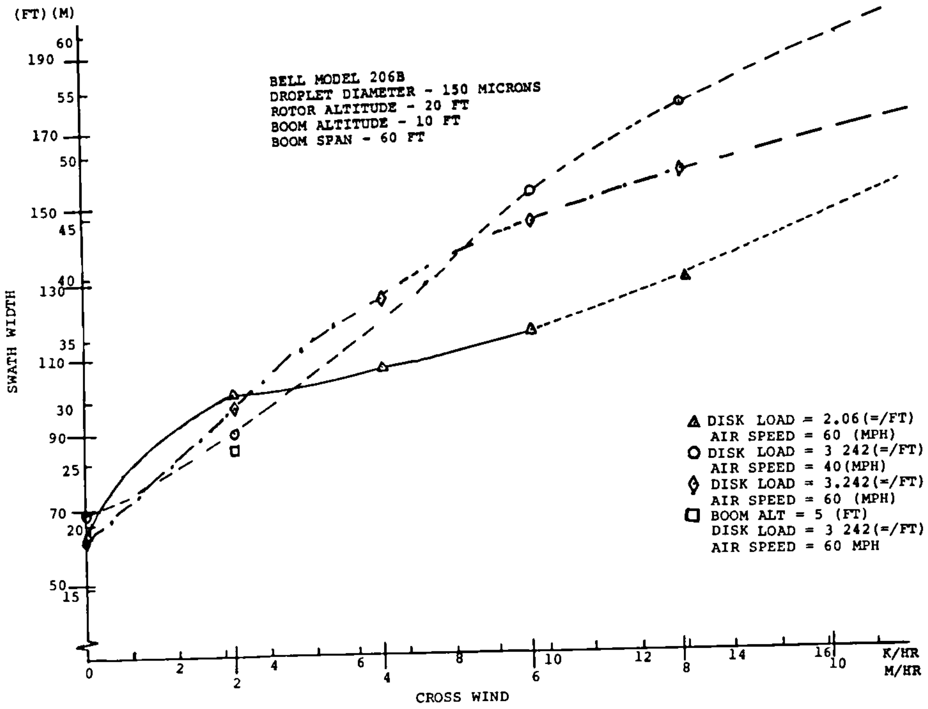

Figure 3. Swath width vs cross wind.

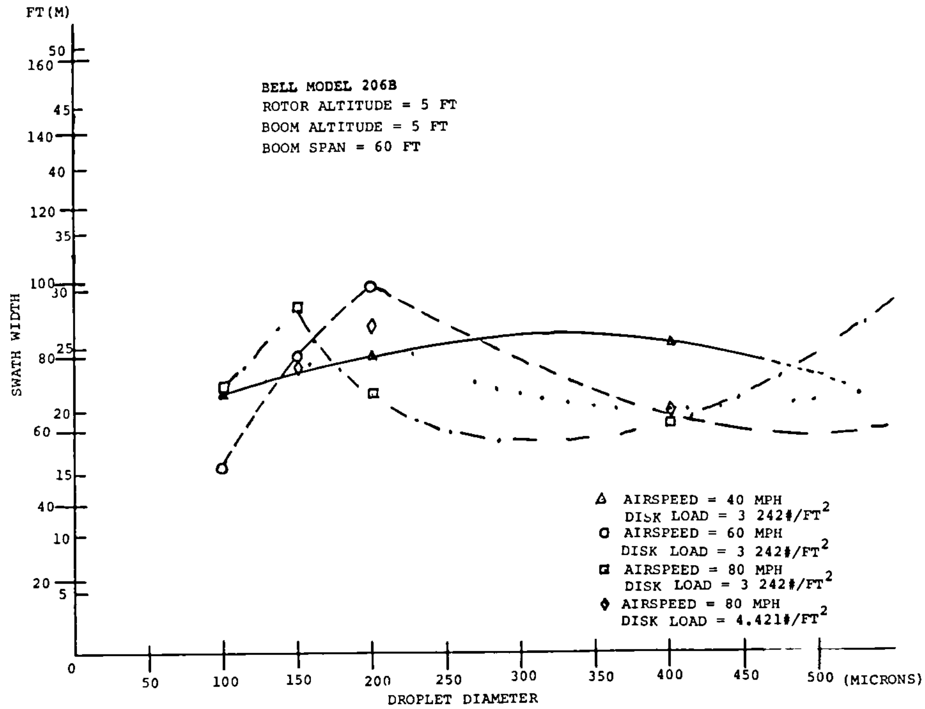

Figure 4. Swath width vs droplet size.

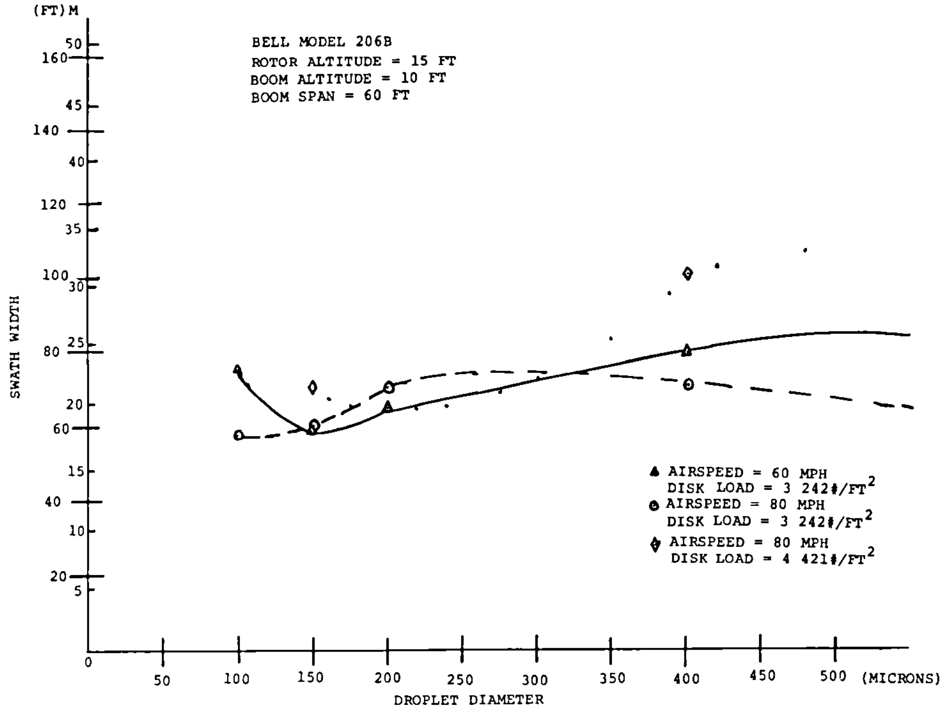

Figure 5. Swath width vs droplet diameter.

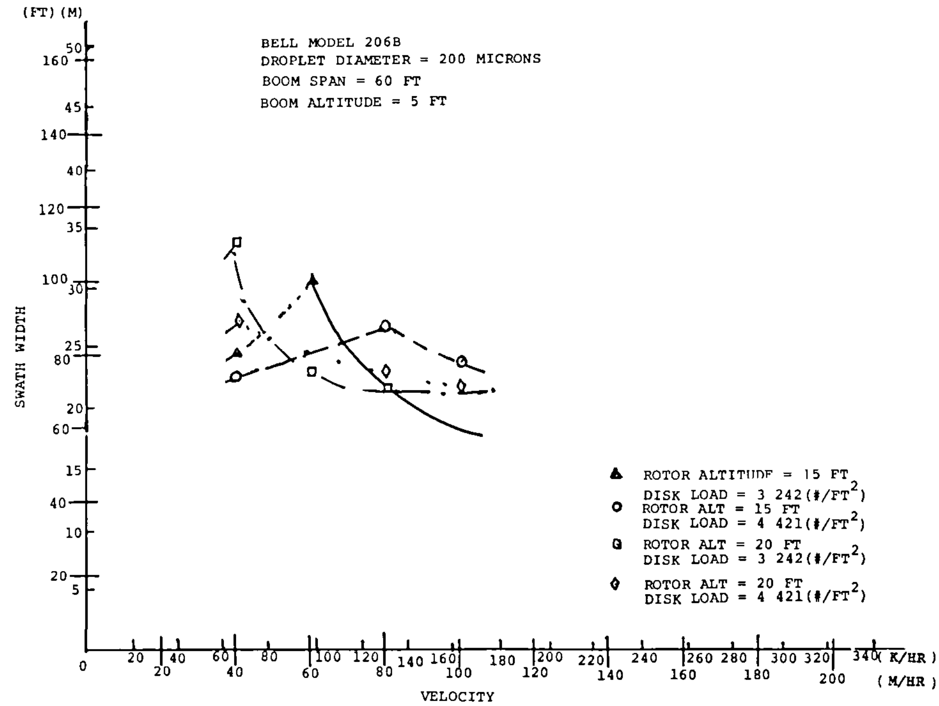

Figure 6. Swath width vs airspeed.

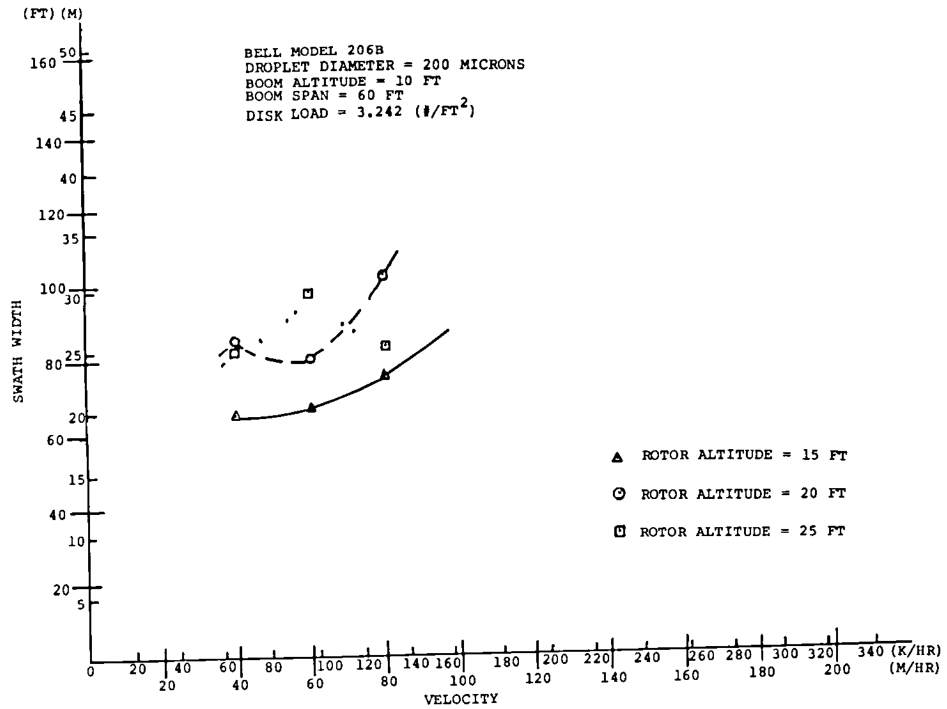

Figure 7. Swath width vs velocity.

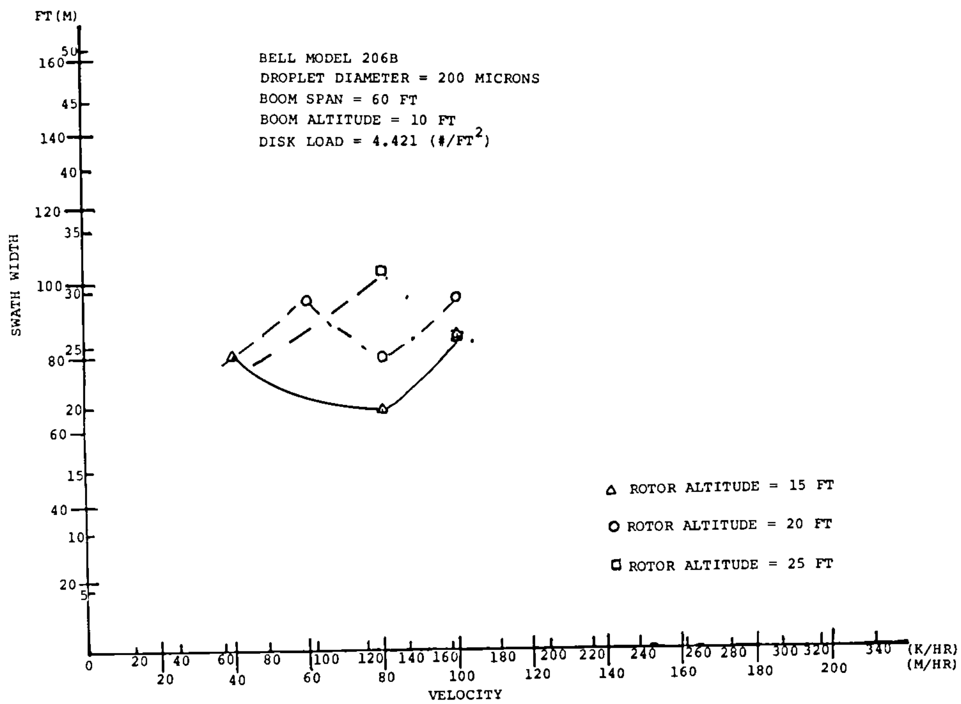

Figure 8. Swath width vs velocity.

Figure 9 shows that more variation (about 125%) occurs at 60 mph for the 15-foot height boom and the 30-foot high rotor location.

The swath width is relatively insensitive to disk loading for a low boom location (5-foot altitude) with increasing spread at higher locations (10 and 15 feet) as shown in Figures 10, 11, and 12.

Figure 13 indicates relatively small changes in swath width for boom altitude variations of from 5 to 10 feet.

Relatively large changes in swath width occur as shown in Figures 14 and 15 as the rotor downwash impinges on the spray wake.

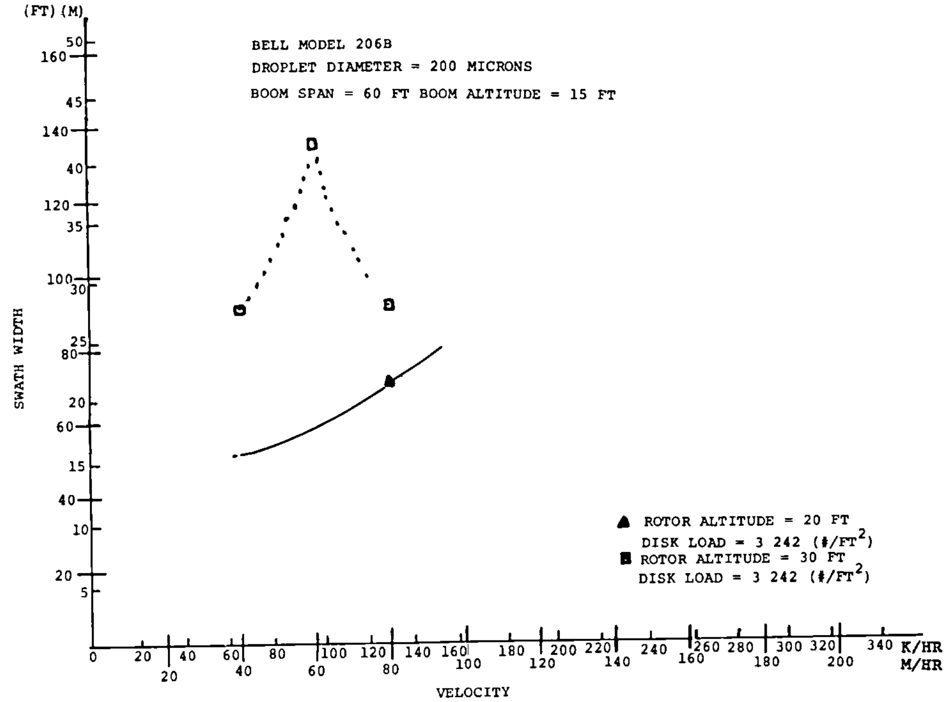

Figure 9. Swath width vs velocity.

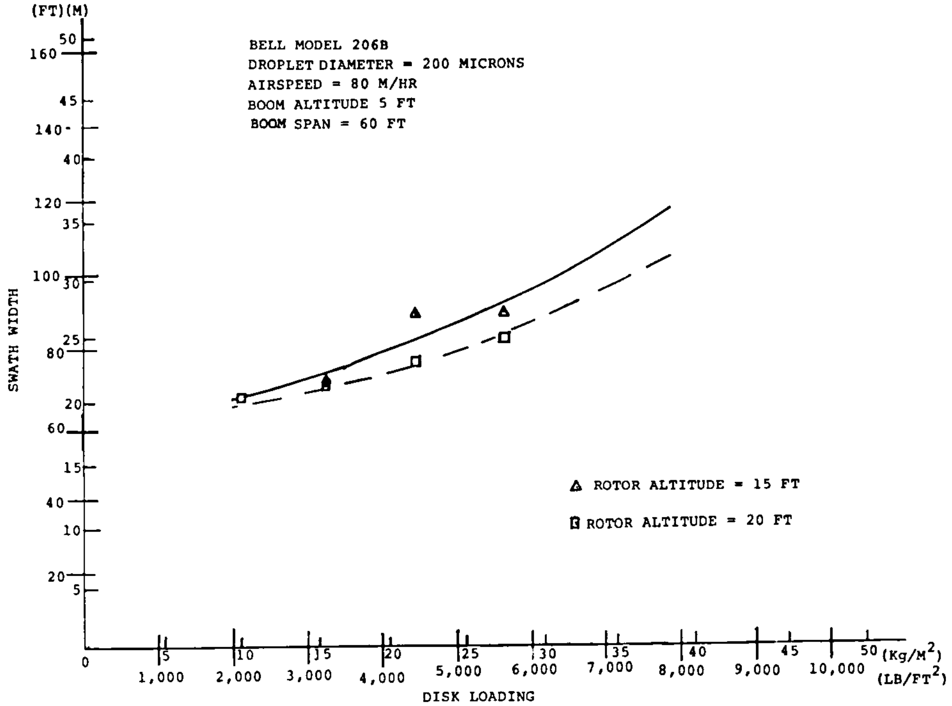

Figure 10. Swath width vs disk loading.

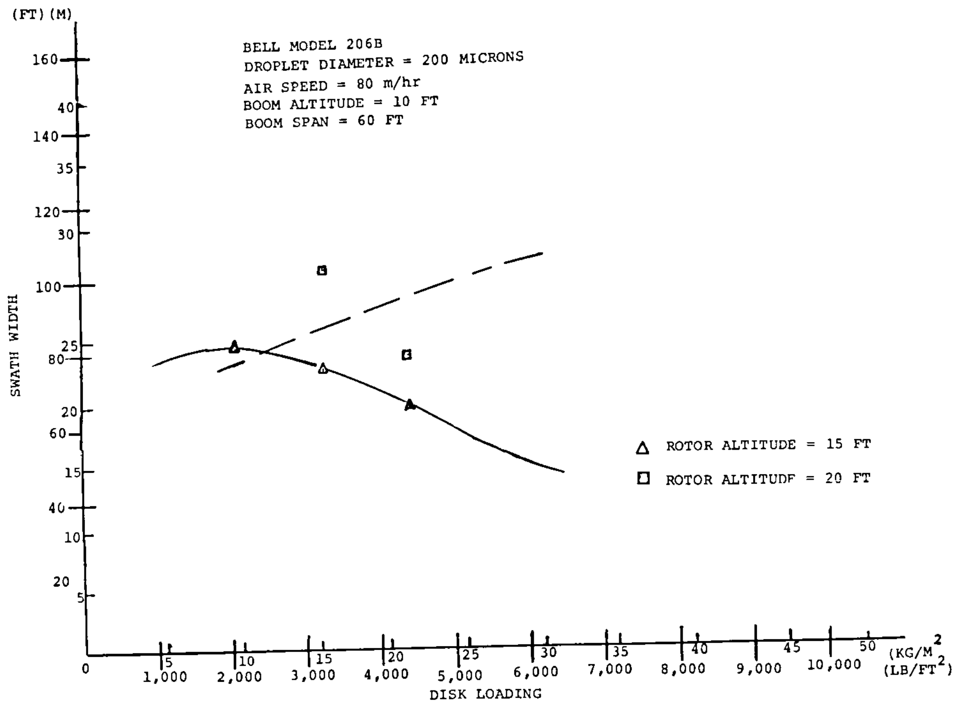

Figure 11. Swath width vs disk loading.

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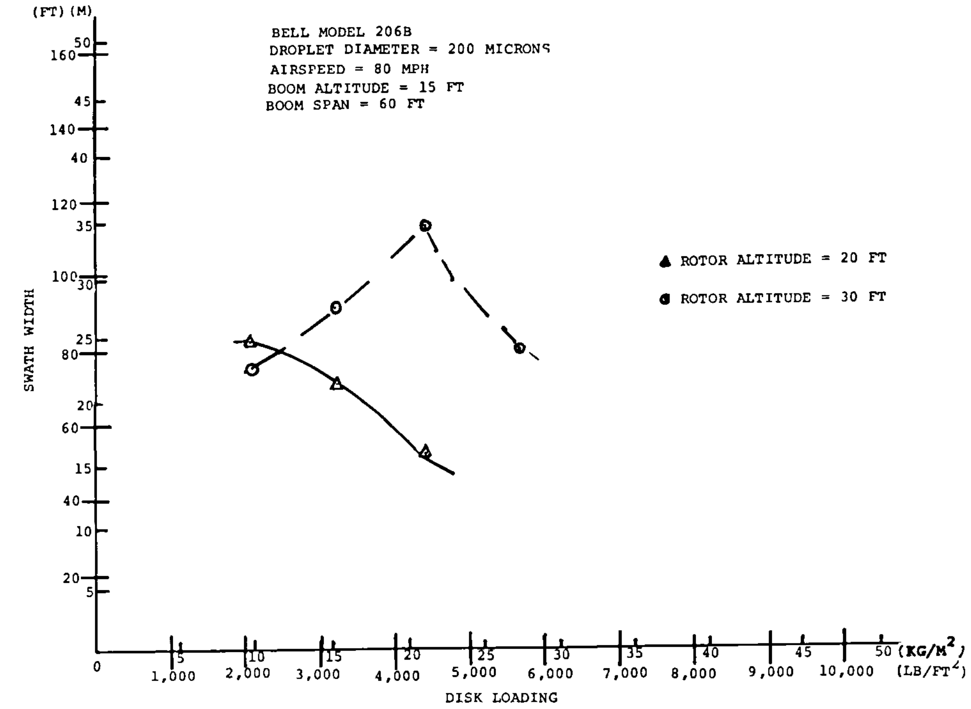

Figure 12. Swath width vs disk loading.

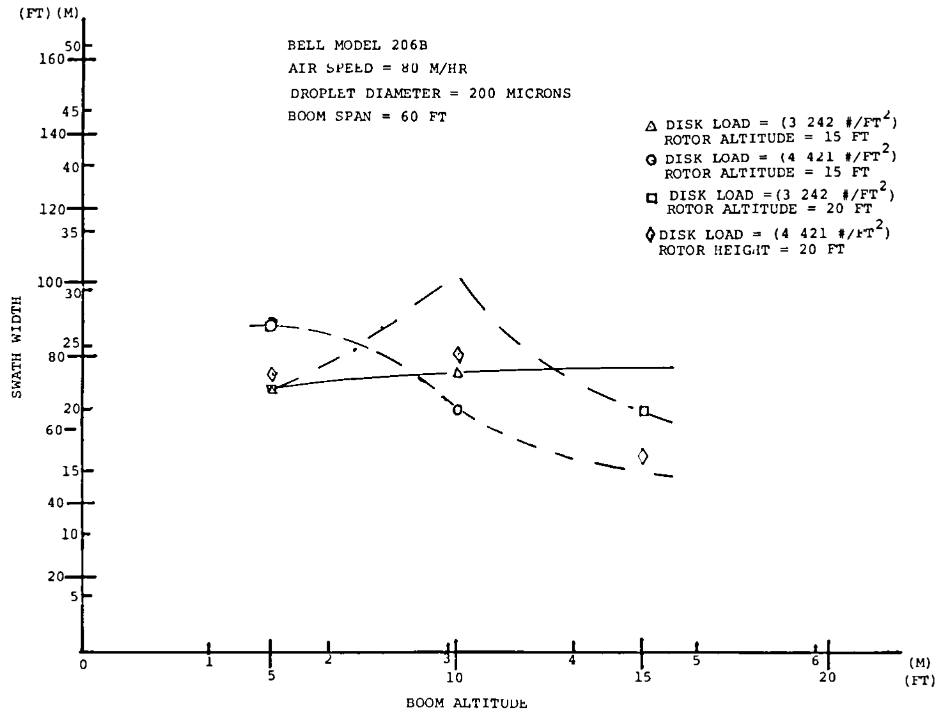

Figure 13. Swath width vs boom altitude.

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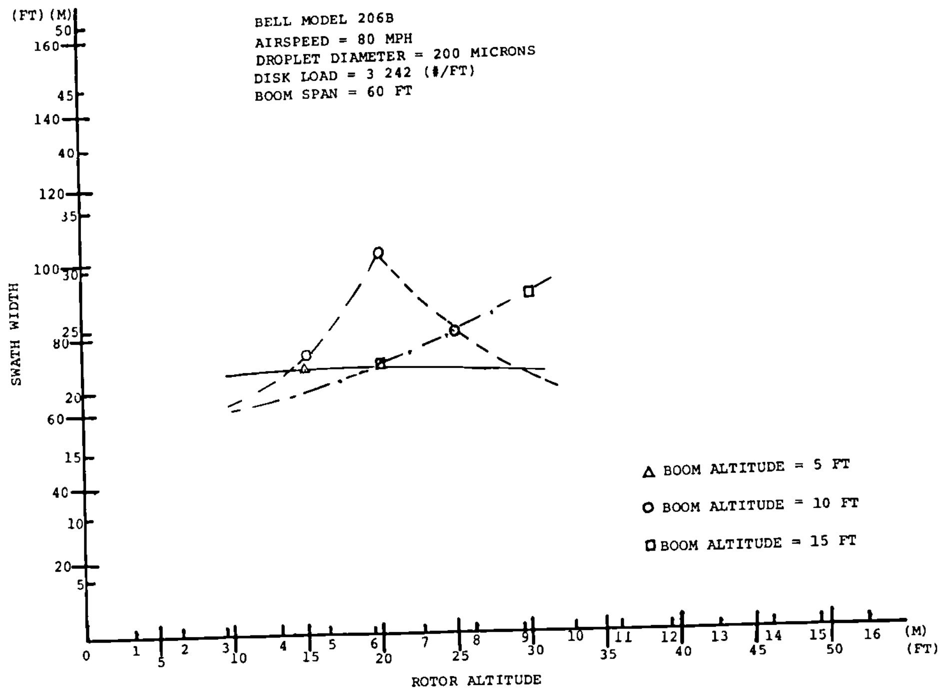


Figure 14. Swath width vs rotor altitude.

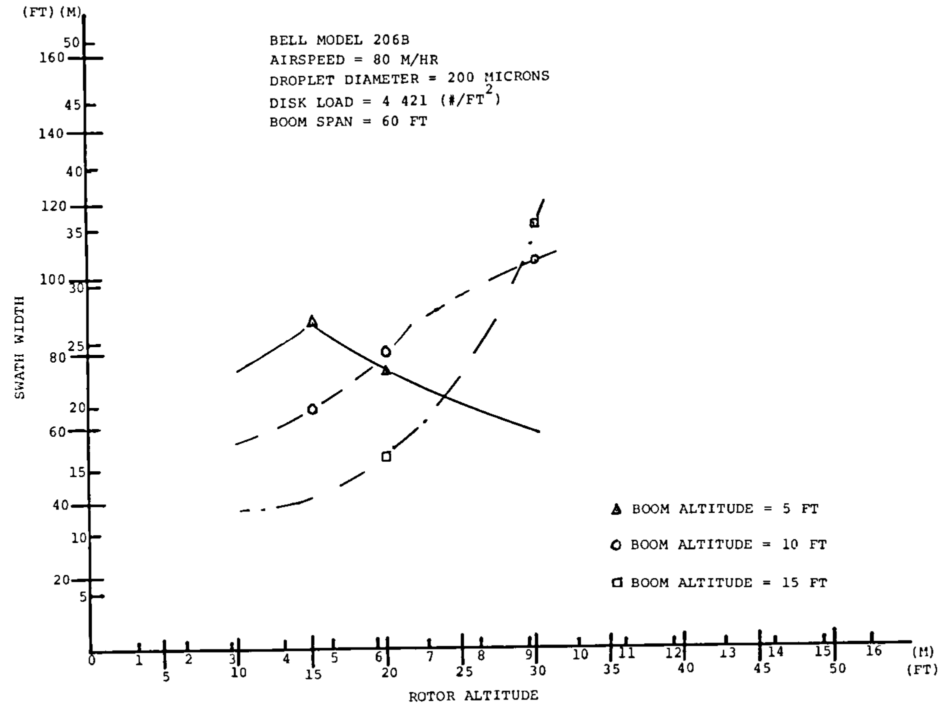


Figure 15. Swath width vs rotor altitude.

General conclusions that may be drawn from these results are as follows:

- Droplet Diameter - Variation of droplet diameter above 100 microns has very little effect on the size of the swath width. Larger particles, however, do not tend to drift as much, creating a more predictable swath pattern. Droplets with a diameter less than 100 microns are affected by any air turbulence and tend to spread out widely with a less predictable pattern.

- Velocity - Velocity seems to have a small effect on the swath width. An increase in the velocity seems to cause a small increase in the swath width. Swath patterns at higher velocities also seem to be more organized, giving a better overall distribution. Swath patterns at low velocities tend to be disrupted by the helicopter wake, making for a very uneven pattern.

- Disk Loading - Disk loading effects seem to be a function of the rotor and boom height. When rotor and boom height are close together, a larger disk loading tends to force the spray downward, decreasing the swath width. When rotor and boom heights are separated, a larger disk loading tends to spread out the spray, increasing the swath width.

  The spraying height above the ground also effects the swath width. Higher disc loadings with boom heights close to ground tend to produce a larger swath width. This is probably caused by the ground effect of the wake of the ship (reference Appendix C)

As standard nozzles give a wide variety of particle sizes; it is apparent that drift of small particles under wind conditions is a prime problem (Reference 5). Studies (References 6 and 7) indicate that about 15 percent of a basic 250μ nozzle spray may be less than 50μ inches in diameter (Bell-shaped distribution). Water particles of such size under high evaporative conditions may never reach the ground, particularly if released from a boom height exceeding 10 feet.

From the above computer study, a swath factor of 1.5 times the installed boom width was selected to estimate the comparative swath widths. This factor is considered conservative and is in the data computations of Appendix A in Tables A-4 and A-5.

2.4.2.3 Productivity

In order to establish the aircraft system potential, a general productivity was defined as follows:

$$P = \text{Productivity} = \frac{\text{Payload x V}}{\text{Gross Weight}}$$

Allowances were made in the determination of the helicopter payload as follows:

Weight of pilot = 200 lb
Weight of fuel = 1/3 normal
Weight of dispersal apparatus = .10 to .12 of weight-carrying capacity (reference Appendix A, Table A-3
Weight of radio and other equipment = 25 lb

A common figure for this allowance value was about 500 pounds which was added to the normal vehicle weight empty. This was then subtracted from the gross weight to define the payload weight of chemical spray or solid loading.

2.4.2.4 Productivity Index

Productivity is defined per the above. Two other indices were used to arrive at the cost/hectare (acre) as follows:

P.I. = Productivity Index
= P/operating cost/hour*

P.I.P. = Productivity Index Product
= P.I. x width of swath and following is:

$$\text{cost/hectare} = \frac{10}{\text{P.I.P.}} \quad \text{Metric Units}$$

$$\text{cost/acre} = \frac{8.25}{\text{P.I.P.}} \quad \text{English Units}$$

*Based on 600 operating hours/year

3. STATE-OF-THE-ART STUDY

3.1 AIRCRAFT STUDY

3.1.1 Aircraft State-of-the-Art

The rotary wing aircraft concerned with Ag use may be classified by the type of engine installed - namely, piston or turbine. Table A-1 lists the piston-powered as utility types and Ag specials. Present Ag specials utilize the dynamic components of standard aircraft (BHT Model 47) as to blades, transmissions, and controls as well as structural components. Weight savings occur in the elimination or reduction of some of the nonessential parts, i.e., one seat and one set of controls, reduction of cabin width, reduced bubble size, etc. Table A-2 does the same for turbine-powered aircraft. Significant geometric, weight, performance, and cost data are included to permit evaluation of the comparative weight fractions, the possible payloads involved, and the operating cost per hour based on a 600-hour yearly operating time. Data are taken from contemporary sources (reference Section 2) and aircraft characteristics and weight fractions are estimated accordingly. Cost data are taken from currently advertised prices of manufacturers and other sources such as BHT internal documents. Figure 16 shows the data treatment to arrive at the estimated costs. Figure 17 is a typical industry presentation chart for estimating the revenue and cost for various numbers of operating hours for the aircraft.

A summary of significant data from the Ag helicopter tables of Appendix A is as follows:

- Weight Fraction Data

  The weight empty fraction is between .5 to .6 of the gross weight for piston-powered helicopters of the utility type.

  Weight empty fraction for Ag specials varies from .475 to .60.

  Weight empty fractions for turbine-powered utility helicopters vary from .40 to .59 (converted piston vehicle) with general values in the .45 range.

  Practical weight empty fractions for Ag special turbine-powered helicopters are undefined as no operational vehicles of this type are presently flying.

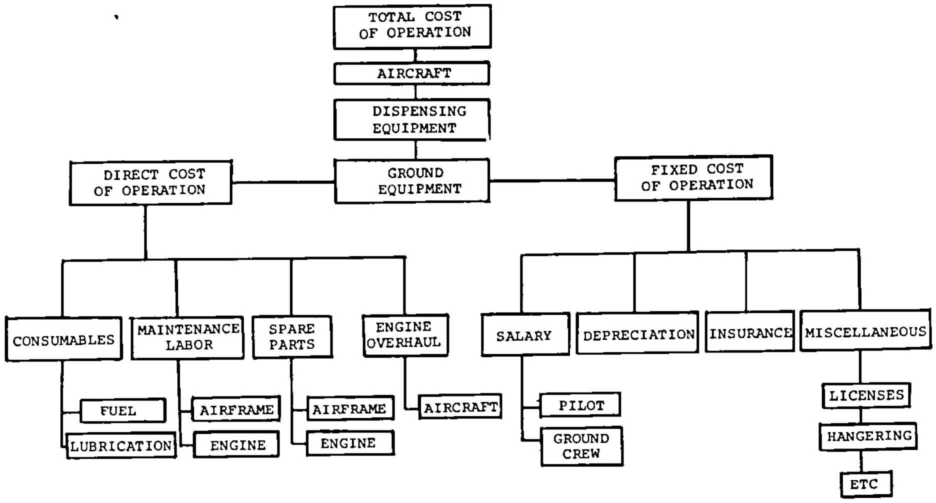


Figure 16. Methodology for determining operating cost.

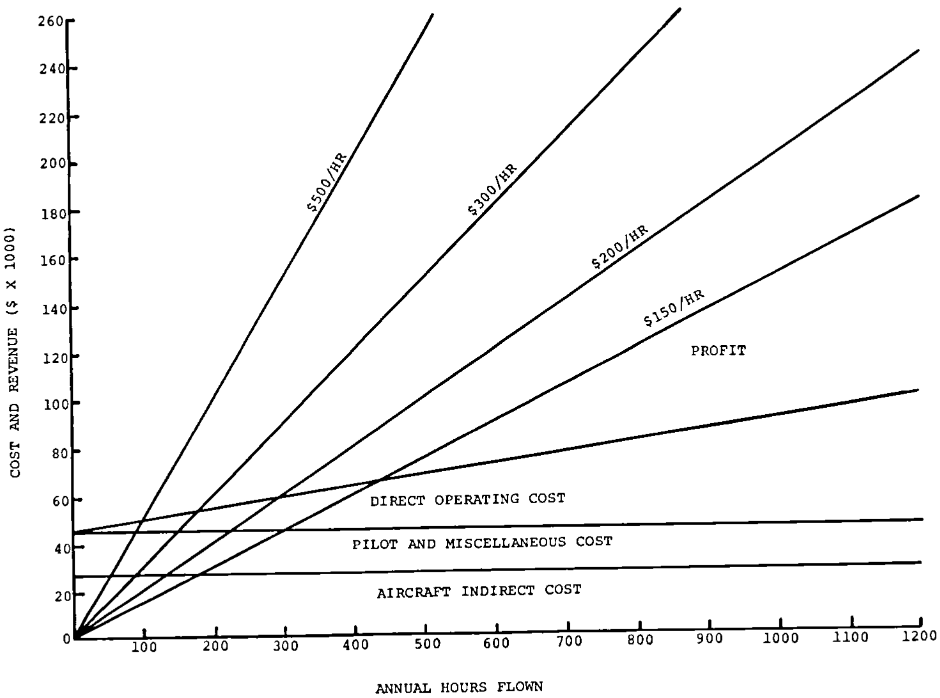


Figure 17. Profitability.

- Productivity:

  - Productivity based on payload, cruise speed, and gross weight indicate that practical values are between 12.0 and 16.0 with a mean of about 15.0 for the utility piston helicopter at best-range cruise speeds.

  - The Ag specials have values lying between 21.0 and 27.0 with a mean of about 25. Although these piston aircraft consist of common BHT dynamic components, it appears that such a single purpose aircraft has a productivity improvement of 25/15 or 1.67 times that of the utility aircraft.

  - From Table A-2, the turbine-powered utility aircraft have values ranging between 26 and 43 with the mean tending to be in the 40+ range.

3.1.2 Productivity Index and Productivity Index Products

These indices, as calculated in the Tables of Appendix A, are used for two purposes:

- P.I. is an indication of the dollar cost/km (mile).

- P.I.P. times appropriate factors indicates the cost/ hectare (acre) for comparative aircraft and equipment configurations (not used for mission analysis). In computing the cost of the missions in Section 8.9, the cost/ hour flying time was used as the basis for comparison.

Costs were calculated as per the above for piston-powered aircraft for both a working velocity (V_W = 60 mph) and the cruise velocity of the vehicle. As the gross weights of most piston aircraft tend to be close to 1362 kg (3000 pounds), plotting cost versus gross weight in this case gives nondefinable trends; therefore, cost was plotted against payload (Figures 18 and 19). The cost per hectare appears to be about $.75 ($.30 per acre) for both velocities due to the small difference between the $V_{working}$ and V_{cruise}. The advantage of the Ag special is noted by comparing the BHT Model 47 Ag 5 at a 272-kg (600-pound) payload and a $1.25/hectare cost ($.50/ acre) to the Continental Copters El Tomcat at a 408-kg (900-pound) payload and $.75/hectare cost ($.30/acre).

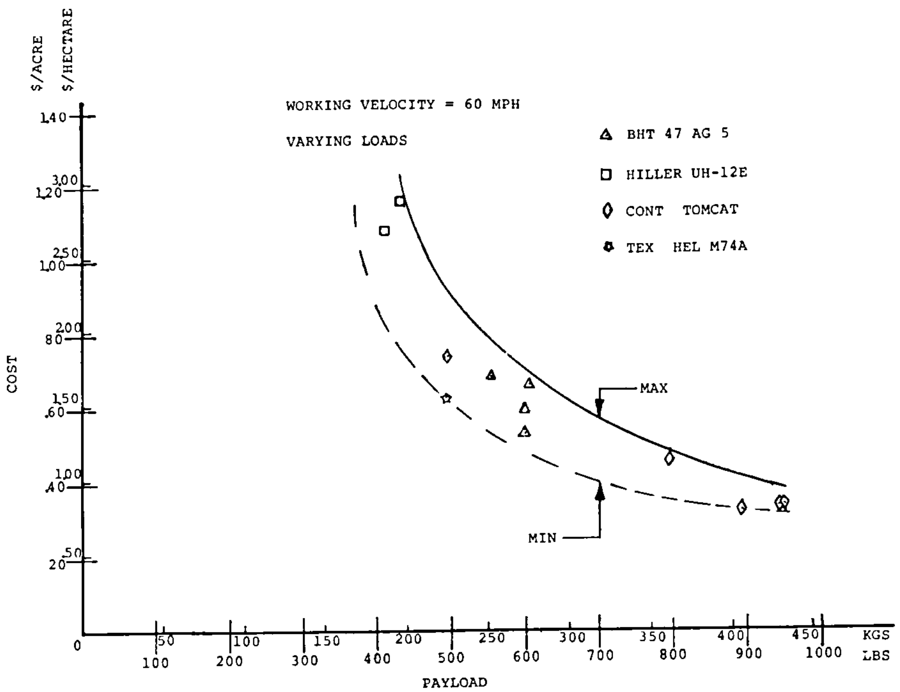


Figure 18. Cost vs payload piston-powered helicopters.

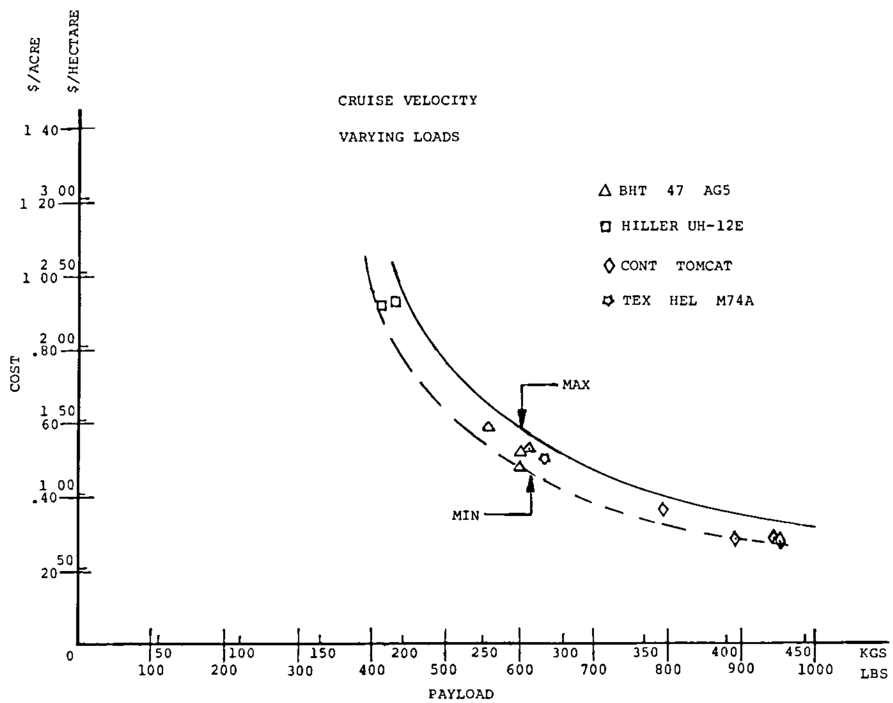


Figure 19. Cost vs payload piston-powered helicopters.

Figures 20, 21, 22, and 23 show plots of the cost/hectare versus the gross weight for turbine-powered helicopters. The $V_{working}$ and V_{cruise} velocities are used with envelope curves shown for both possible minimum and maximum costing. An interesting effect with attached tanks (Figure 20) is the increase in maximum cost at higher gross weights. Minimum costs appear to vary from $.75 to $1.87/hectare ($.30 to $.75 per acre) depending upon gross weight for the condition 3S. Maximum costs vary from $2.25/hectare ($1.00/acre) to $15.00/ hectare ($6.00/acre) at high gross weight. For the liquid slung load of Figure 21, minimum costs run as low as $.75/ hectare ($.30/ acre) and maximum as high as $6.20/hectare ($2.50/ acre).

For equivalent conditions, Figures 22 and 23 show the costs of dispensing solids by external hopper stowage and by slung pod.

3.2 EQUIPMENT

3.2.1 Matching Equipment

In the state-of-the-art review of aerial agricultural equipment, the subject was treated in accordance with the functional breakdown of the various portions of the apparatus, i.e., ground or air handling equipment (reference Figure 2). Equipment installations were listed by manufacturer for both liquid and solid dispensing systems, and efforts were made to classify these by use. The various weight fractions shown in Table 17 were computed based on the ratio of the empty equipment installation weight to its loaded weight. These values were used in estimating the payload capabilities of the various aircraft.

Matching of available installations to specific aircraft was accomplished from equipment manufacturers data as well as other sources. These matches are shown in Tables A-4 and A-5. It may be noted that the equipment often either limits the amount of material or provides a greater capacity than the vehicle can lift. In these situations, the study effort best matches equipment to aircraft or, if pertinent, selects systems in accordance with need. Figure 24 shows the weight fractions of the equipment based on the gross weight of the apparatus plus its load for internal, external, and slung systems. Figures 25 and 26 are a further breakdown of the system shown in Figure 12 for reviewing equipment requirements for solid, liquid, slung or mini-liquid spraying.

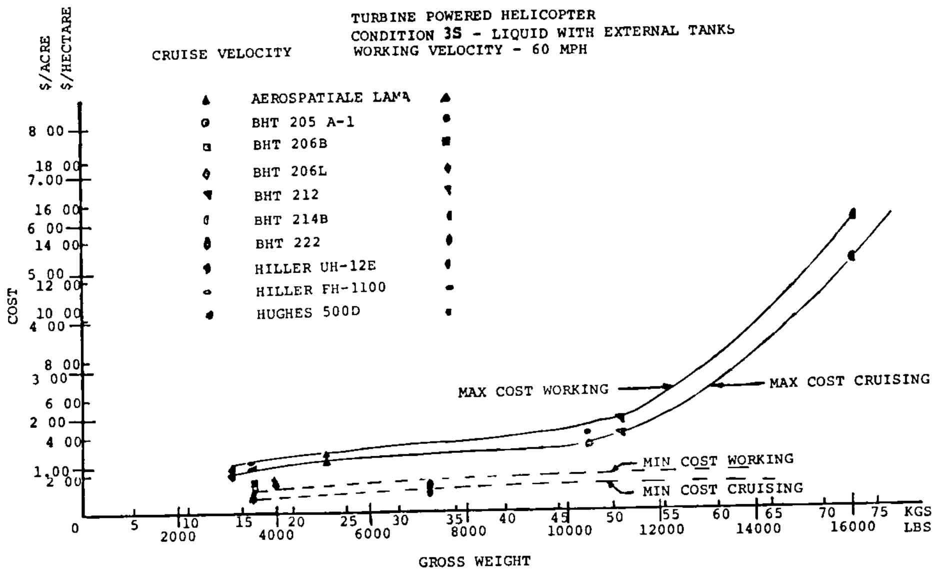


Figure 20. Spraying cost vs gross weight.

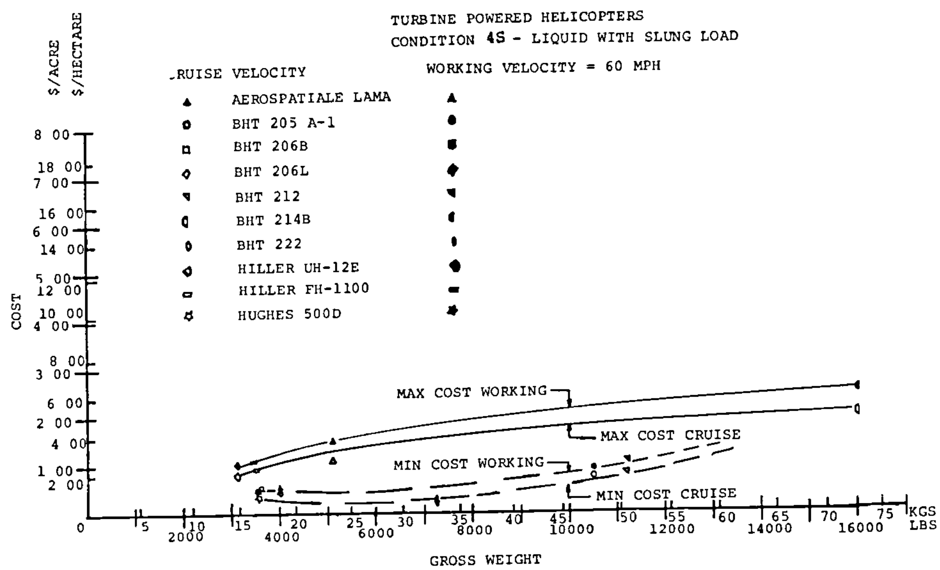


Figure 21. Spraying cost vs gross weight.

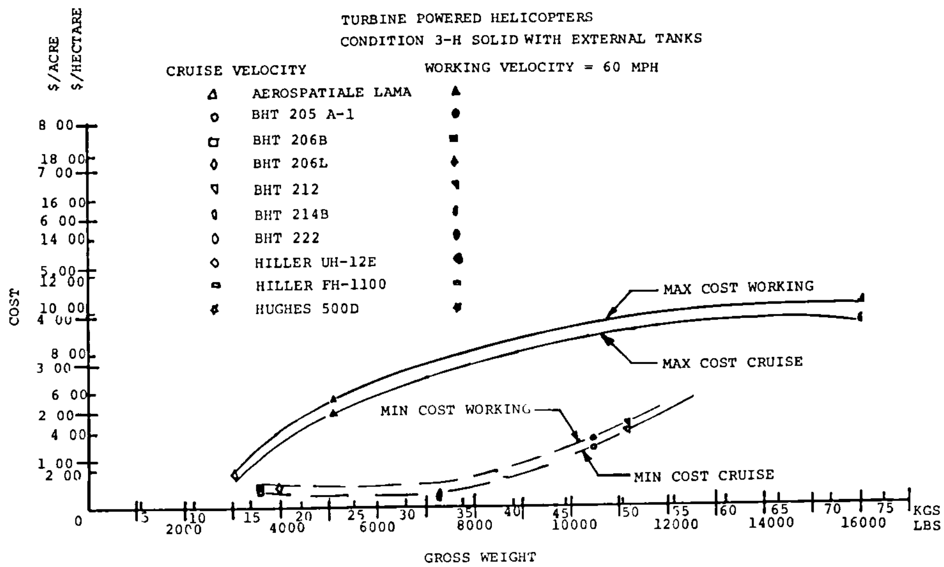


Figure 22. Dispersal cost vs gross weight.

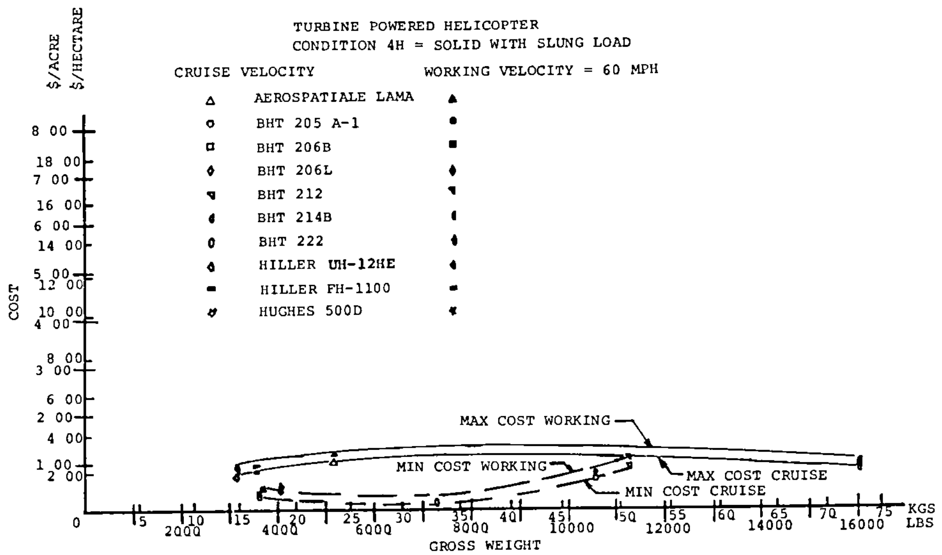


Figure 23. Dispersal cost vs gross weight.

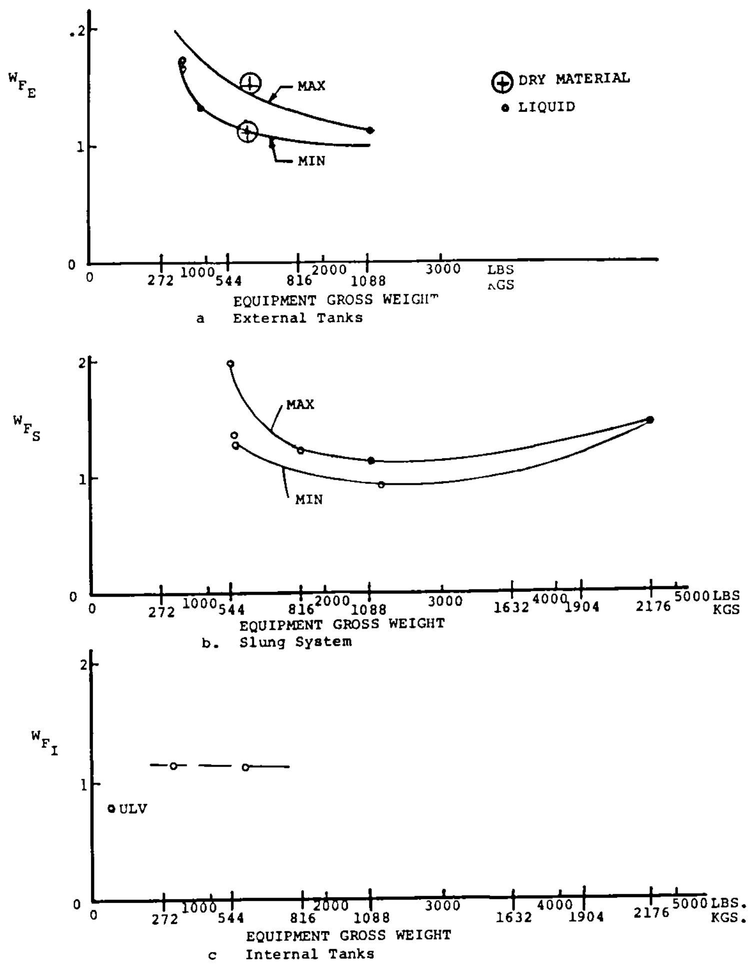


Figure 24. Ag equipment weight fractions.

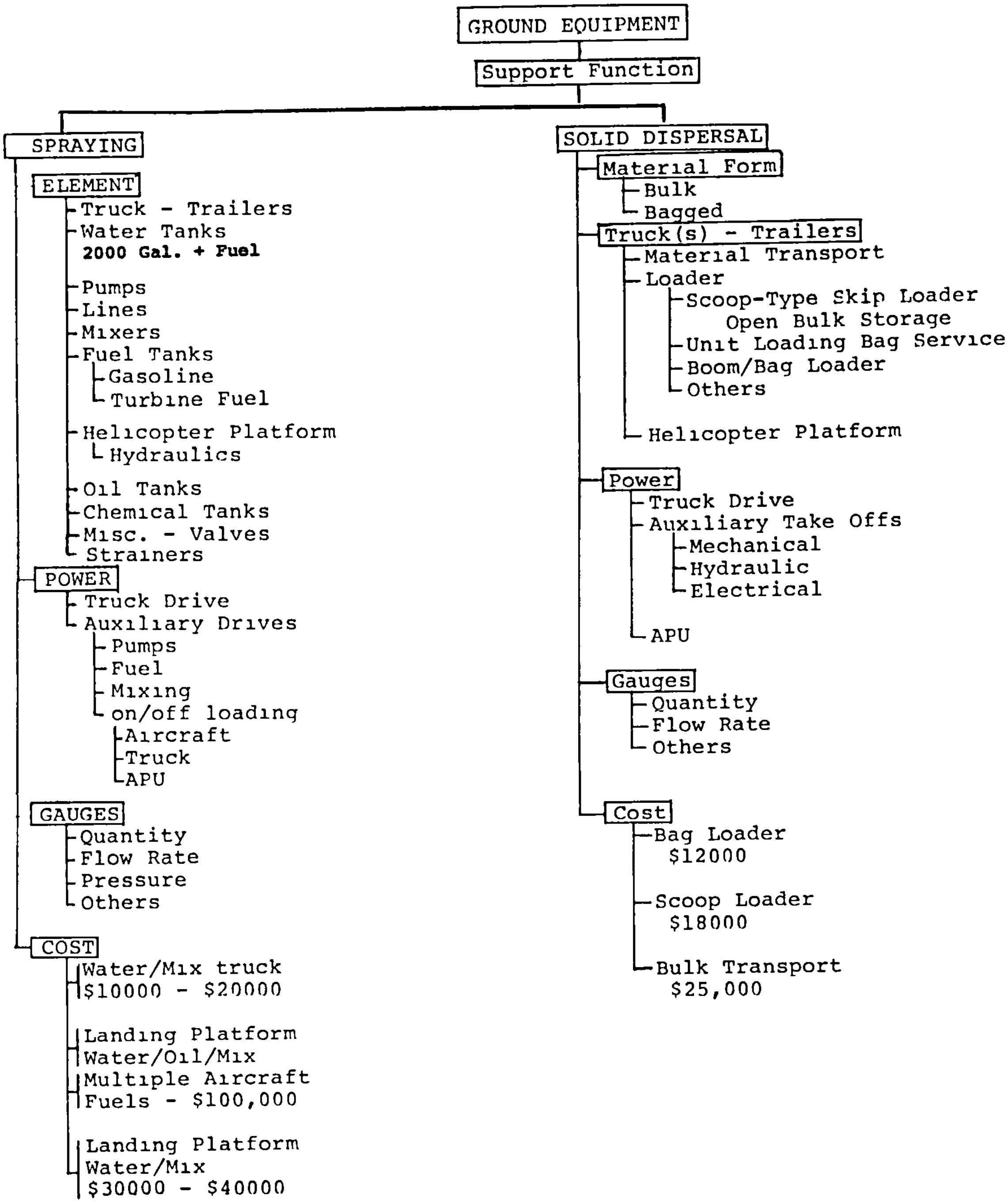


Figure 25. Ground equipment.

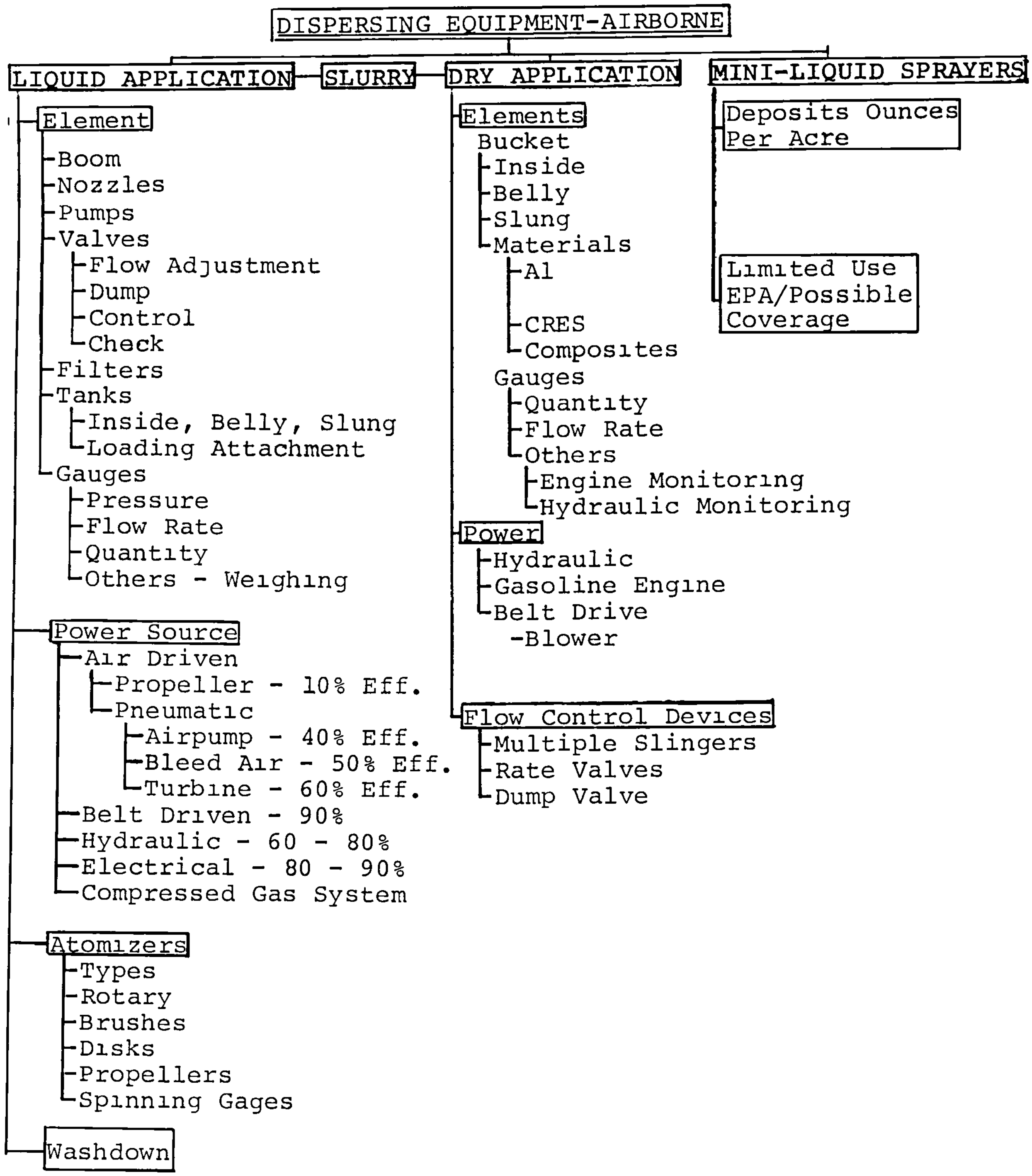


Figure 26. Dispersing equipment-airborne.

3.2.2 Nozzle Systems.

Reference 3 lists the various contemporary and experimental nozzle types as the following:

- Jet
- Floodjet
- Microfoil™
- Hollowcone (with cone plate)
- Teejet™
- Hollowcone (without cone plate)
- Fullcone
- Flatfan
- Twinfluid
- Rotary
- Spinning disk
- Pulsed jet
- Electrostatic generator

Descriptions of these systems are in the NASA references as well as other sources such as references 6 and 7. Data are available on operational characteristics of each, and each nozzle system has an area in which it performs best. Unfortunately, off-optimum requirements limit effectivity of these systems. For example, switching coverage rates often requires changing of nozzle characteristics. Changes in basic droplet size, evenness of distribution in the swath, clumping, streaking, delivery rates, penetration effects - all vary nozzle effectivity and, in some cases, quite drastically. Basic to all spray nozzles is a bell-shaped distribution curve of droplet size. Fixed droplet size nozzles may not operate at all outside of a limited range.

It appears there are three viable alternatives for performing the desired objectives. One would be to design adjustable nozzles which produce uniform-size droplets of a selected diameter (100-500 microns) without fines, (2) remove the fines from the spray, or (3) control their pathway.

3.2.3 Marking Devices

Various devices are sold for the purpose of marking the rows which are to be treated. These devices represent an effort to replace human flagmen who are subject to the hazard of poisons, expensive to use, unreliable or ineffective under certain circumstances, and represent an unacceptable time charge on the duty cycle. For some purposes, no markers are required as for small fields of row crops where the treatment swath may be defined by pilot observation and memory.

On the other hand, where a large forest area is treated, defining the treated versus the nontreated areas may be most difficult. In this case, rather sophisticated electronic systems may be in order.

Table 7 lists some commonly available marking devices referenced to the name of the manufacturer. It may be noted that sophisticated electronics offers features at a price which may be most valuable under certain circumstances. Where the mission treatment is in a fixed area (Operator A for example) located within a defined radius of action, three of the marking units may be permanently located in relation to the home base.

Knowing these marking points and the fields to be treated, there are several brands of the sophisticated electronic devices which will indicate accurate swath locations for pilot action; night flight operations thus become possible. The cost of these devices approaches the purchase price of some of the piston-powered Ag specials; therefore, application tends to be with the more advanced and higher payload turbine-powered systems. A particular advantage is use under marginal conditions of daylight or visibility to permit treatment that could not be delayed without crop damage.

3.3 INTERFACES

The interfaces of the dispersal equipment with the helicopter are influenced by the location of the tanks or hoppers, by the nature of the dispersed materials, and the type of ground handling equipment required. Figure 27 shows some of the problems inherent with these systems. Helicopter designs require the disposable loads to be as close to the center of gravity of the vehicle as reasonably possible. This includes the fuel, the spray material or dispersed solid, as well as other items such as pilots and passengers. Unfortunately, the transmission, rotor, and controls intrude as these must be located in the same area. Normally, with a single main rotor machine, the top of the vehicle is so cluttered with apparatus that provision for the top filling of a solid single dispensing hopper (internal tankage) would be most difficult. Exterior tanks (one on each side) overcome this disadvantage as do slung tanks or pods.

Figure 28 shows various loading techniques for solids, liquids, and slurries from hand to mechanical handling of dispersed materials.

TABLE 7. TYPES OF MARKING EQUIPMENT

MFG.	MODEL	TYPE	WT. Kg Lb	USED ON	APPROX COST $	REMARKS	GROUND PERSONNEL REQUIRED
AIR AG, IND WALLA WALLA, WASH	AUTOMATIC FLAGMAN MODEL 4 MODEL 5	A	 (14.4) (8)	B, H HU, AS	$500	PAPER STREAMERS DROPPED BY A/C. FLAGS WEIGH 1.32 OX WITH 100 TO 280 CAPACITY	N
COMPRO-AVIATION INC., GOODLAND, KANSAS	DRIFT ER	A	-	U	-	DRIFT & MARKING INDICATOR-SMOKE	N
DEL MONTE TECHNOLOGY, INC. EULESS, TX	FLYING FLAGMAN	AE GE	(40)	U	$50,000	HELICOPTER MAY POSITION GROUND UNITS - 300' TO 50 MI LENGTHS	N
MID CONTINENT HAYTI, MISS	TRACKER	A	-	U	-	DRIFT & MARKING INDICATOR-SMOKE	N
MOTOROLA SCOTTSDALE, ARIZONA	MINI RANGER III	AE GE	-	B, AS	$44,000 $4,000/MO RENT	HELICOPTER MAY POSITION GROUND UNITS 1300' TO 50 MI LENGTHS	N
SUTTON AERIAL SERVICES	PATHMARK	G	-	G	-	ACCURATE MEASURE OF TRUCK/ MARKER POSITION BY WHEEL MEASUREMENTS	Y
TRANSLAND, INC. HARBOR CITY, CALIFORNIA	QG	A	-	U	-	RADIO CONTROLLED WINCH FLAG UNITS - GROUND SET UP - AIR CONTROLLED	Y

B = Bell Helicopter Textron
H = Hiller
HU = Hughes
AS = Aerospaciale
U = Universal Use Capability
Y = Yes
N = No

E = Electronic
A = Airbourne
G = Ground

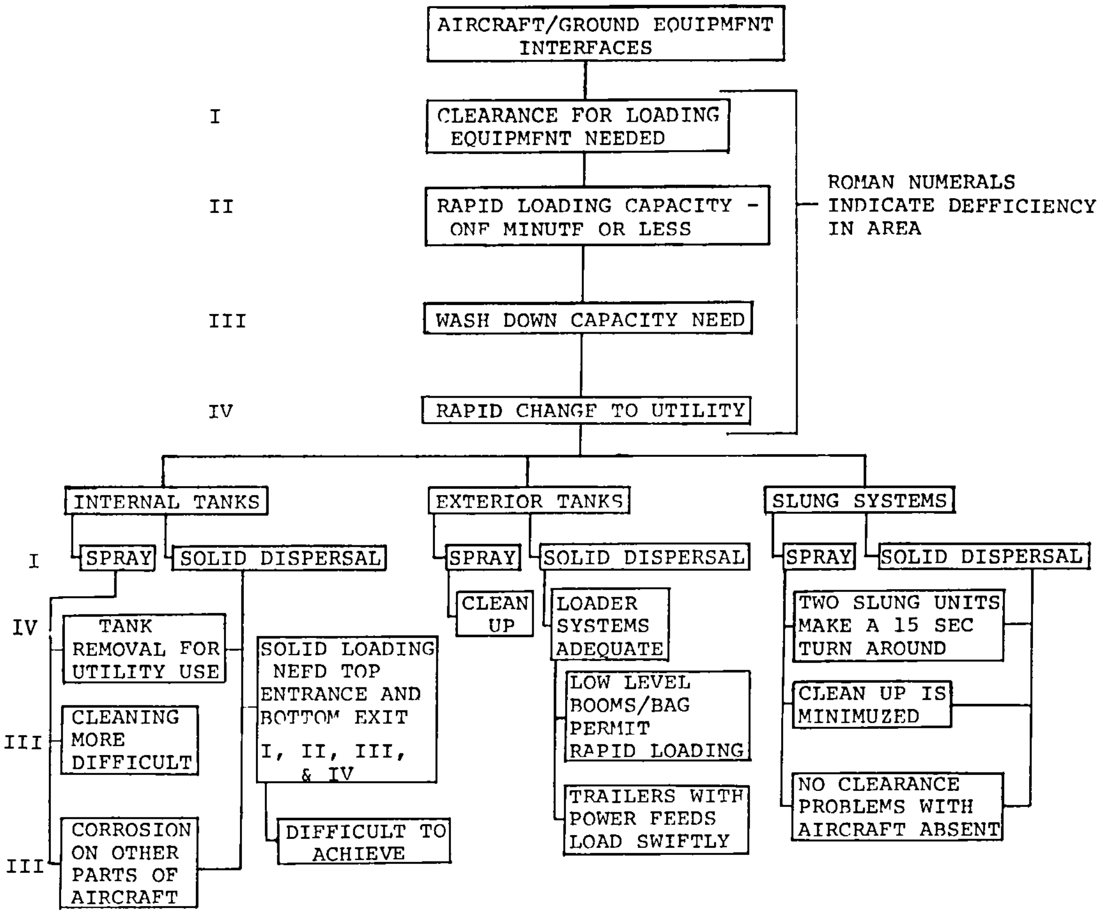
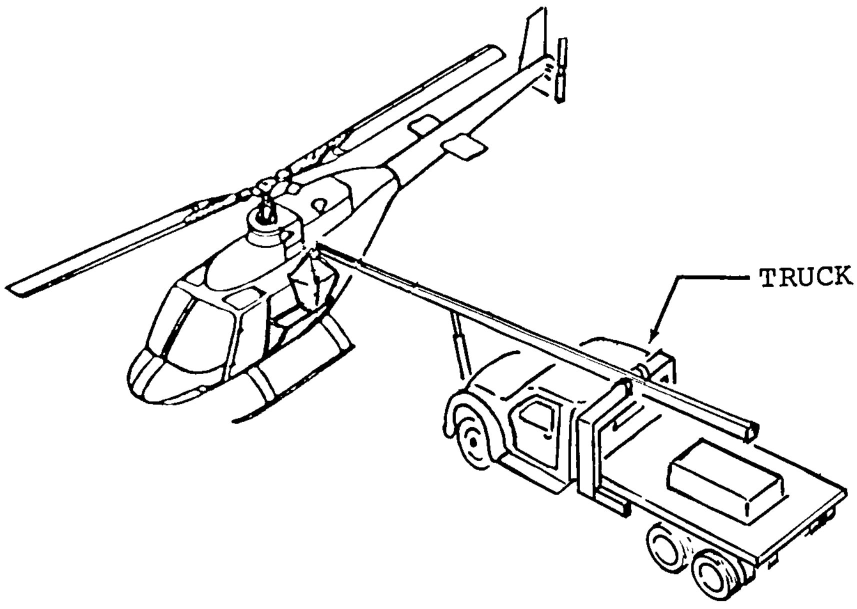


Figure 27. Interface problems.

a. Solid or Liquid Loader - Truck/Bay or Truck/Hopper



b. Solid Loader - Trailer Loader

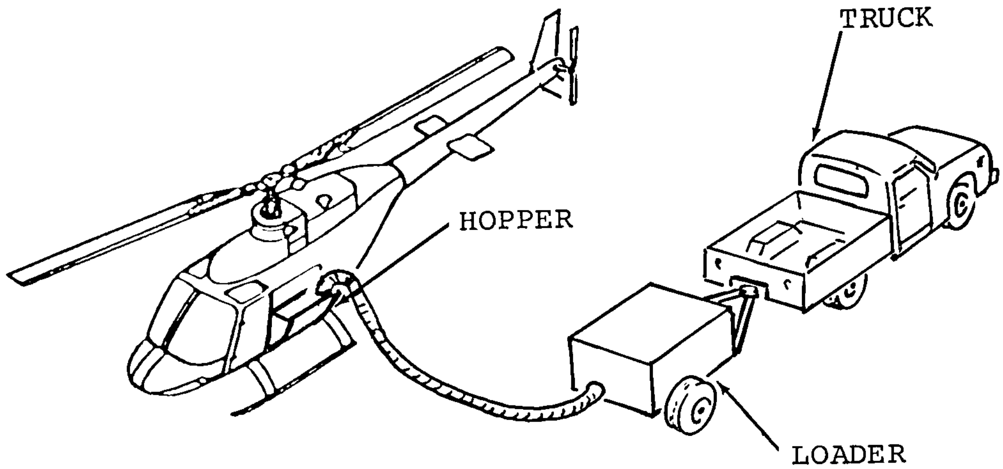
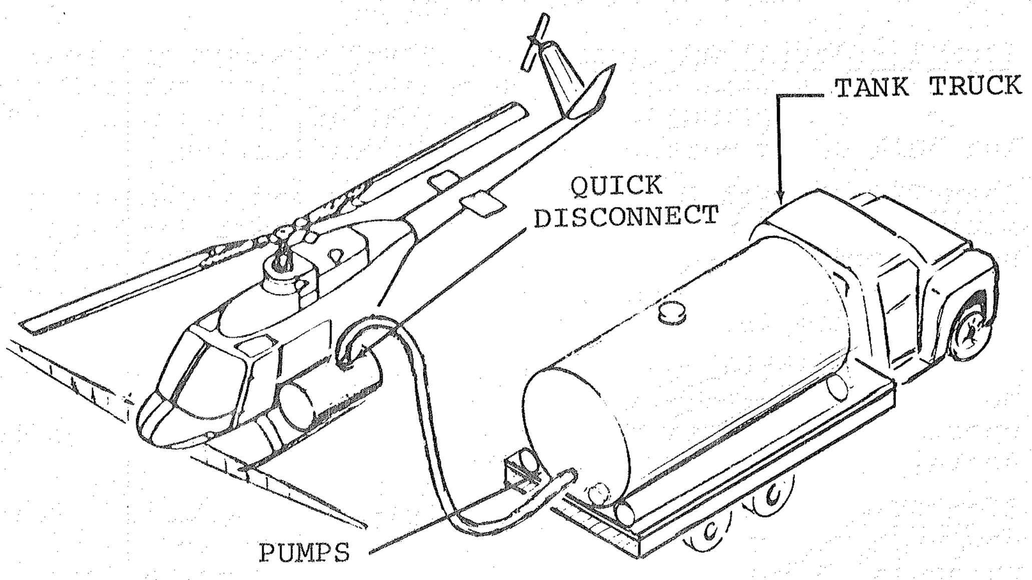
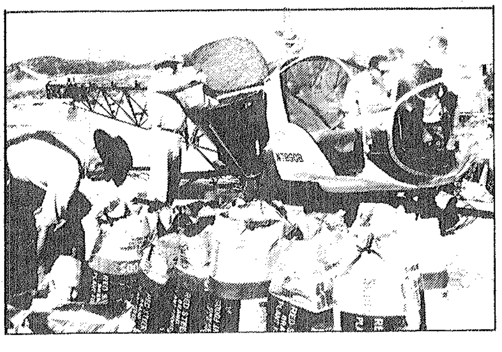


Figure 28. Loading interface.

c. Liquid Loading



d. Solid or Liquid Loading Manual and Aircraft Pickup



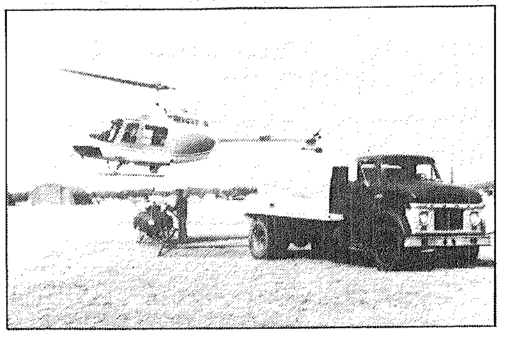


Figure 28. Loading interface (Concluded).

3.4 AG USE OF HELICOPTERS

The morphological chart of the uses of Ag helicopters (Figure 1-1) permits a functional classification of the system related to requirements for special equipment as follows:

- Item 1 - Aerial Applications. These systems are most complex as a wide variety of materials of toxic and non-toxic nature (liquids, dusts, granular, live) are used. The bulk of Ag work is in this classification.
- Item II - Aerial Surveys. The camera and the mapping equipment (radar, altimeters, Loran C, heat devices) associated with this Ag function are of limited utility for other agricultural purposes, although some may be of use for Item III.
- Item III - Aerial Observation and Patrol. Systems to monitor the ecology or particular crops reflect the specialized devices necessary to properly observe while aerial patrolling.
- Item IV - Production of Air Turbulence. Normally, rotor downwash velocity is considered sufficient for these purposes; however, it is conceivable that extra jet blower equipment (heated or unhe [illegible] jets) may be required for some uses such as modifying s[illegible] wakes, harvesting nuts, or orchard frost control. [illegible]ght flight capability may also be required.
- Item IV - Support Function. Equipment to fulfill the support function might be a portable landing field, soil solidification apparatus, or possibly a fiberglass-sprayed area to permit dustless landings and takeoffs to prevent crop damage. Resupply of application materials, fuel, water, etc., by air would fall into this classification. Logistics for the material handling equipment is also included.

The purpose of classification is to select present and potential uses for this study, analysis, and design work. Item I represents the bulk of aerial applications, and BHT study work was in this direction.

The economic viability of an optimized single-purpose machine (most efficient to perform a given function) has been questionable in the past; therefore, study of this factor was included. Figure 29 indicates possible design choices for aircraft system operational use with economic practicality increasing from low in Column A to high in Column D. Information from the study has been factored into computer predictions of the weight, performance, and cost penalties associated with near design optimization for multiple use, alternate use, and universal use systems (Reference Sections 4.1, 5, and 8).

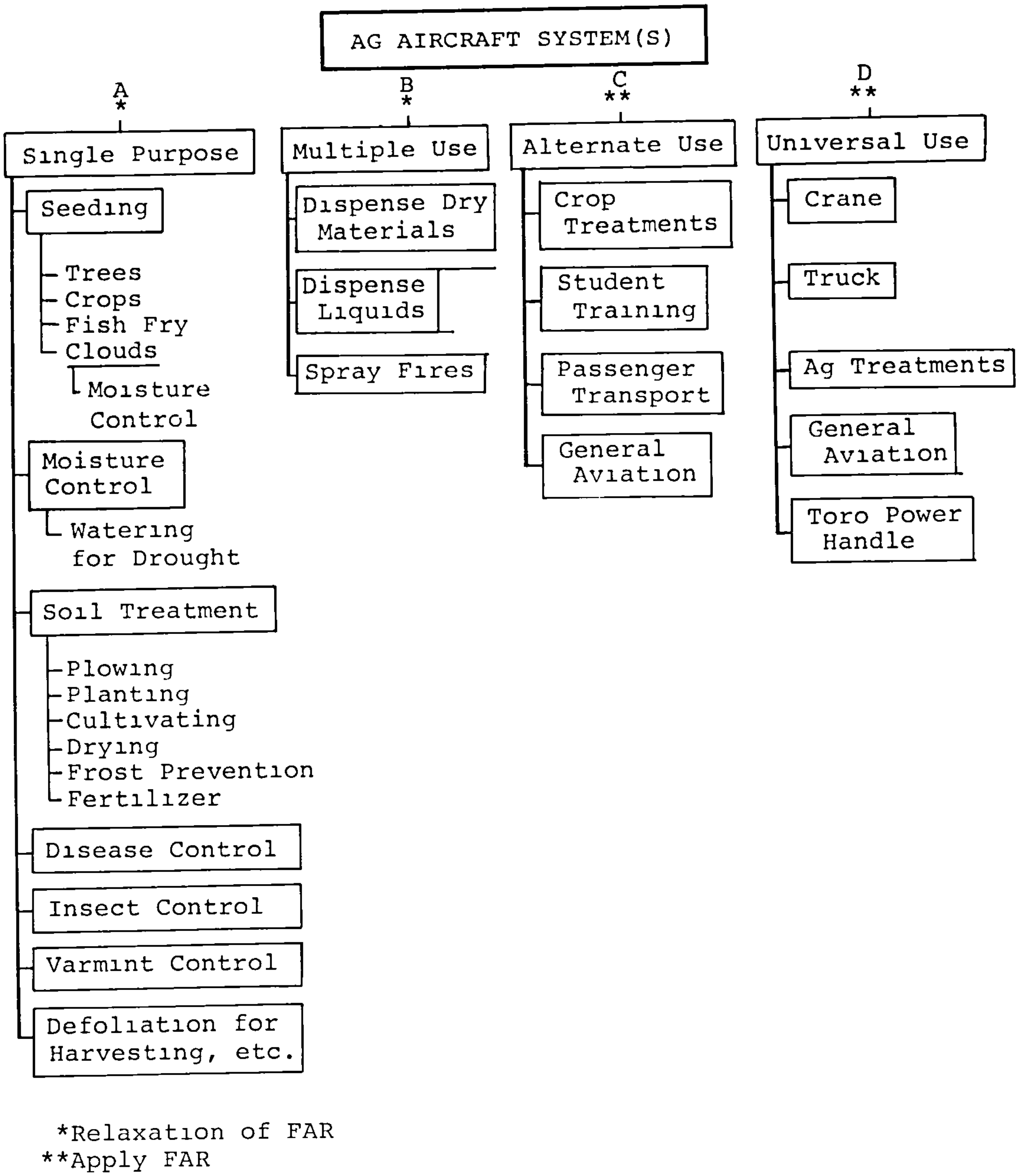


Figure 29. Aircraft use chart.

4. OPERATIONAL CONSTRAINTS AND DOWNWIND DISPERSAL

Variations in swath width with velocity are shown in Figures 3 through 15 for different locations of the rotor, boom, disk loadings, and flight path heights.

The effect of aircraft spraying velocity change is to modify the swath width, either increasing or decreasing it in accordance with the operating conditions. If the aircraft is flying at a fixed ground speed, then the delta wind velocity either must be added to or subtracted from the mean speed, i.e., a changed vehicle air velocity must occur for a constant ground speed. This change in swath width with velocity necessitates a variation in row spacing to maintain an even coverage. Turn on or shut off of the spray becomes more complex because of the wind velocity effects. From Figure 6 it would appear that for the rotor altitude of 4.92m (15 ft) that a change from 56.3 to 128 km per hour (60 to 80 mph) would make the swath width vary from 30.48m to 23m (100 to 70 ft) minimum width. To maintain a uniform ground coverage, this would require a change in the flow rate. To summarize the above:

- Upwind or downwind vehicle motions change the swath width, either expanding or narrowing it depending upon conditions.
- Row spacing must be changed for upwind versus downwind operations.
- Dispersal rates must be adjusted for upwind/downwind operations to obtain uniform coverage.
- Turn on and shut off means must be closely controlled with an anticipated wind direction estimation.

It can be seen from the above that low specific limits to the permissible operable wind speed should be set for up and down wind operations. The pilot burden tends to be excessive in anything but large, easily treated fields which may be better handled by airplanes. Two possibilities exist for such operations. One would be to use a two-man crew consisting of a pilot and copilot sprayer/controller; the pilot would modify the flight in accordance with conditions and the copilot would adjust and monitor spray coverage.

The second approach would be to develop an onboard computer to monitor conditions and instruct the pilot as to how and where to fly for spray control.

Operations in winds of up to twenty miles per hour might thus be accomplished provided the droplet size is accurately controlled to eliminate fines. It appears that straight upwind and downwind directions would have to be flown by the aircraft (Figure 3). A change from 3.22 km per hour (2 mph) crosswind to 9.70 km per hour (6 mph) shows a swath width change from 29.5m to 49.2m (90 to 150+ ft). This represents about a 3.8-degree change in wind heading which could readily occur in a few seconds under variable wind conditions. Even coverage would require a complete and rapid adjustment of the spray rate under this situation.

It would seem that other modes of operation might be considerably easier to conduct. Night flight may offer a better approach to the problem of winds. In many areas, winds drop just before darkness and stay low until shortly after sunrise. Much treatment occurs in these dawn and dusk times. This also offers a large night operation window for crop treatment, particularly when the crop is not sensitive to evening moisture effects and if the proper helicopter apparatus (dispersal system, row marking equipment, and proven night flight instruments) could be available. Methodology to identify the fields to be treated, to indicate obstacles to be avoided (houses, wires, poles, trees, etc.), to identify the loading and unloading points, to indicate the treatment flight paths, and to differentiate between the treated and untreated areas is in order.

Some of these are difficult factors particularly in terms of a low-cost field treatment requirement. Radar, sonic, laser, and microwave wire indicators do not promise to be inexpensive devices for this purpose. Operation of such, while flying the aircraft, guiding the wake, and dispensing Ag materials does not appear simple.

From the above, it appears that the required gains to achieve successful up- and down-wind operations and/or effective night flight capability will be a rather expensive and difficult achievement.

One of the big constraints to Ag operations is the control of the swath. This consists of drift control, turn on and turn off of the row spray, coverage control, penetration, control of streaking, as well as other pertinent factors associated with the nature of the treatment and the crops. Drift control may be achieved by several methods as follows:

- Rigid control of particle size to eliminate fines (50m or less diameter)

- Spreading solids impregnated with herbicide, pesticide, or fungicide

- Directing a curtain of air outside the swath to limit its spreading while injecting a nucleating agent (dust, powder, etc.) to gather the fines together

- Increased surface tension sprays of higher density materials, i.e., slurries for control of droplet sizes

- Inertia-separator booms described in Section 10

- Others from NASA reports (References 1,2,3 and 4)

Figure 30 shows a morphological chart defining some of the overall constraints to the Ag aircraft business. As noted, these constraints occur from nature; federal, state, and local governments; the aircraft; its equipment; operational limitations; and costing. A further breakdown of these factors is made in Figures 31, 32, 33, 34 and 35.

One constraint factor which affects the treatment of a particular field is its geometry (reference Figure 36). The size and shape of the crop area of a particular field is often determined by what is apparent whim if contour plowing is not required, i.e., the rows may be oriented with no regard to the prevailing winds or the aspect ratio of the field. Irregular shapes (trapezoidal, triangles, rhombic rounds, etc.) are quite often the rule rather than the exception.

Figure 36 shows the effect of shape, defined as aspect ratio, AR, (field length divided by field width or swath length) on the time required to spray a 10.1 hectare (25 acre) field at 96.5 km per hour (60 mph) using a 30.48m (100 ft) swath width. For a 10.1 hectare (25 acre) plot, 30.48m (100 ft) wide, (AR approaches zero) it would require about 120 seconds spray of the area at 96.5 km per hour (60 mph). The same area with an aspect ratio of 10 would take over 500 seconds (over 4 times longer). This aspect ratio effect has been factored into the selection of fields for typical study missions and the layout of the fields during a duty-cycle day of treatment.

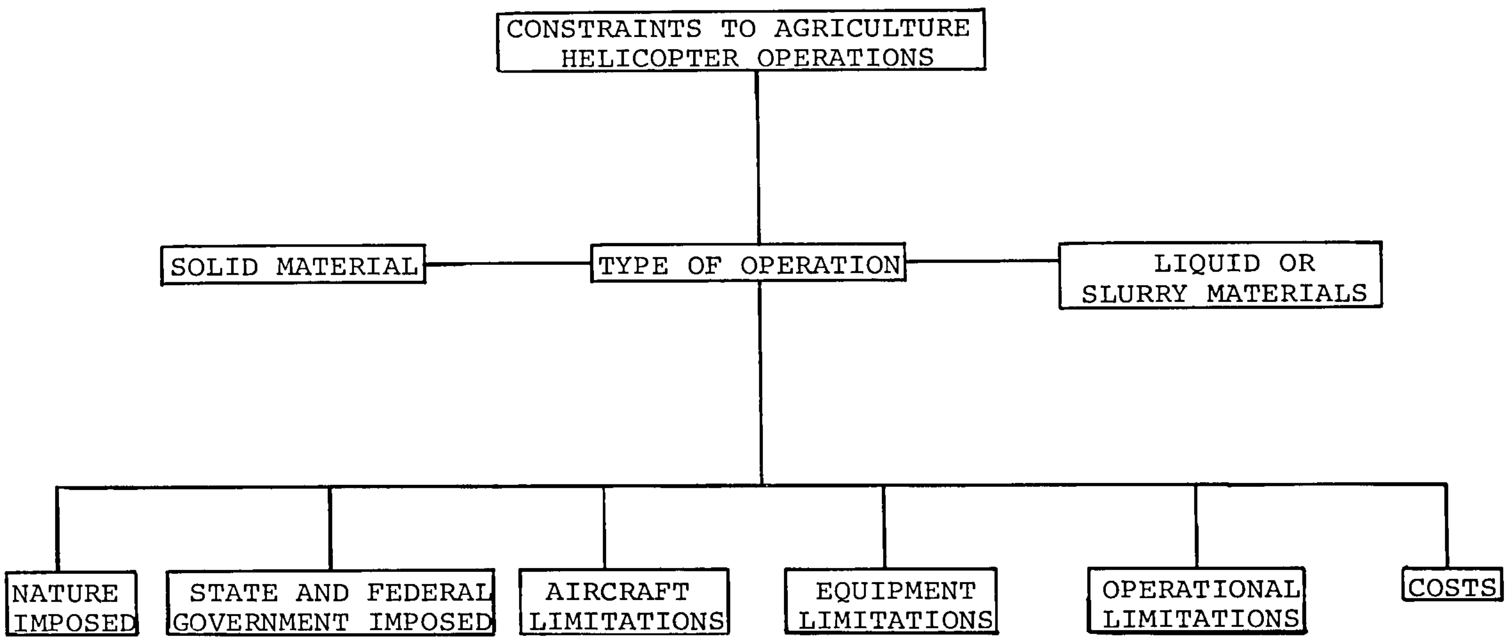


Figure 30. Constraints to agriculture helicopter operations.

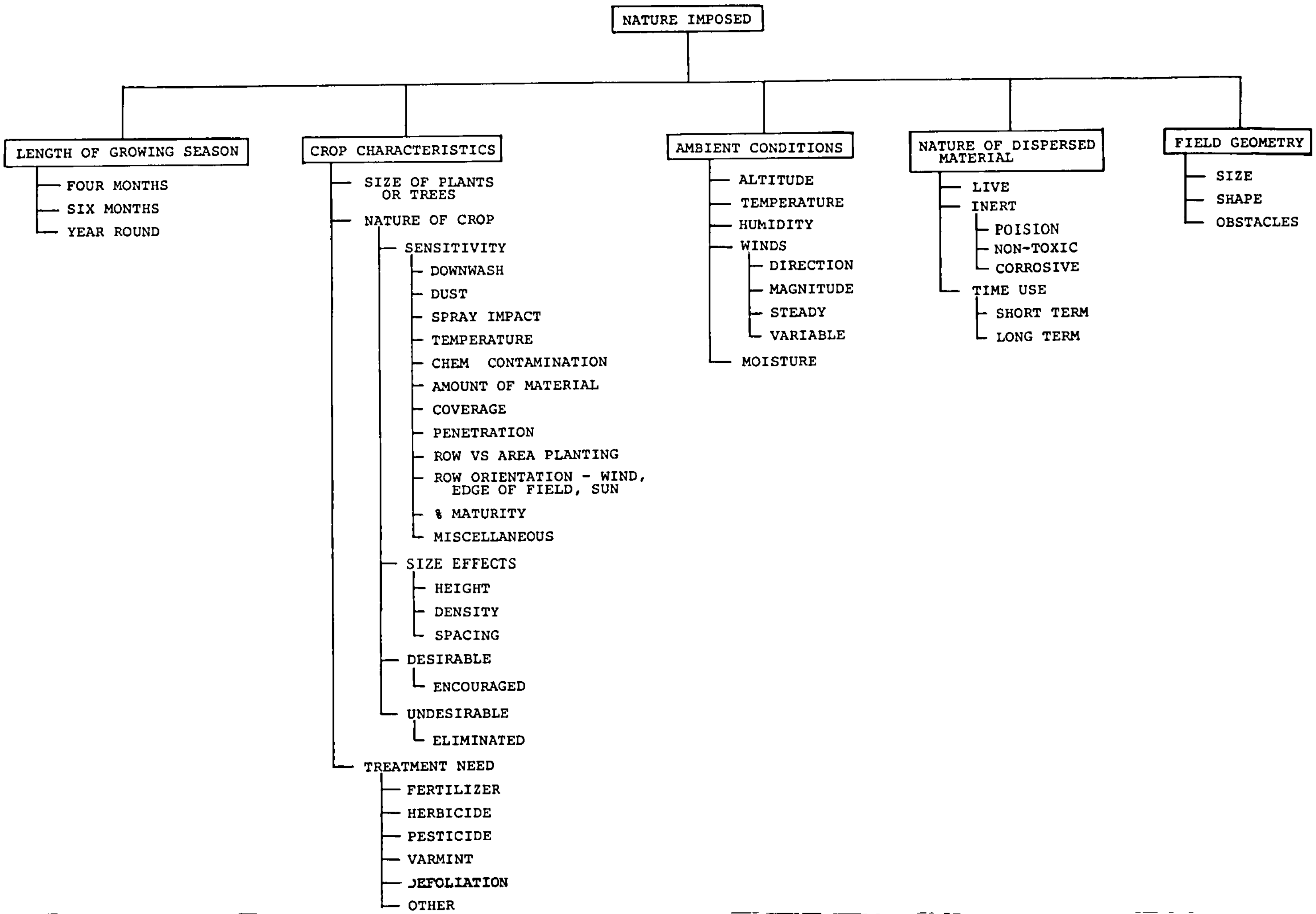


Figure 31. Nature imposed limitations.

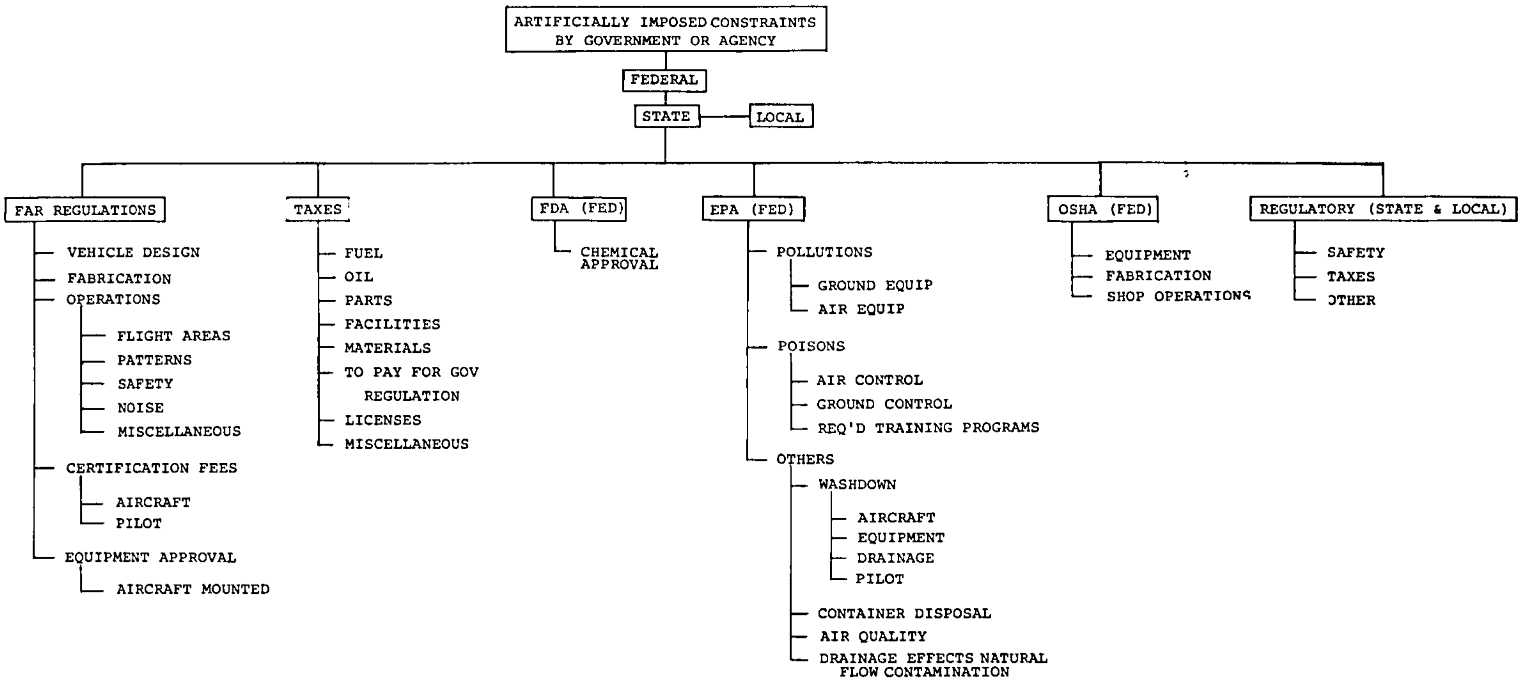


Figure 32. Artificial restraints.

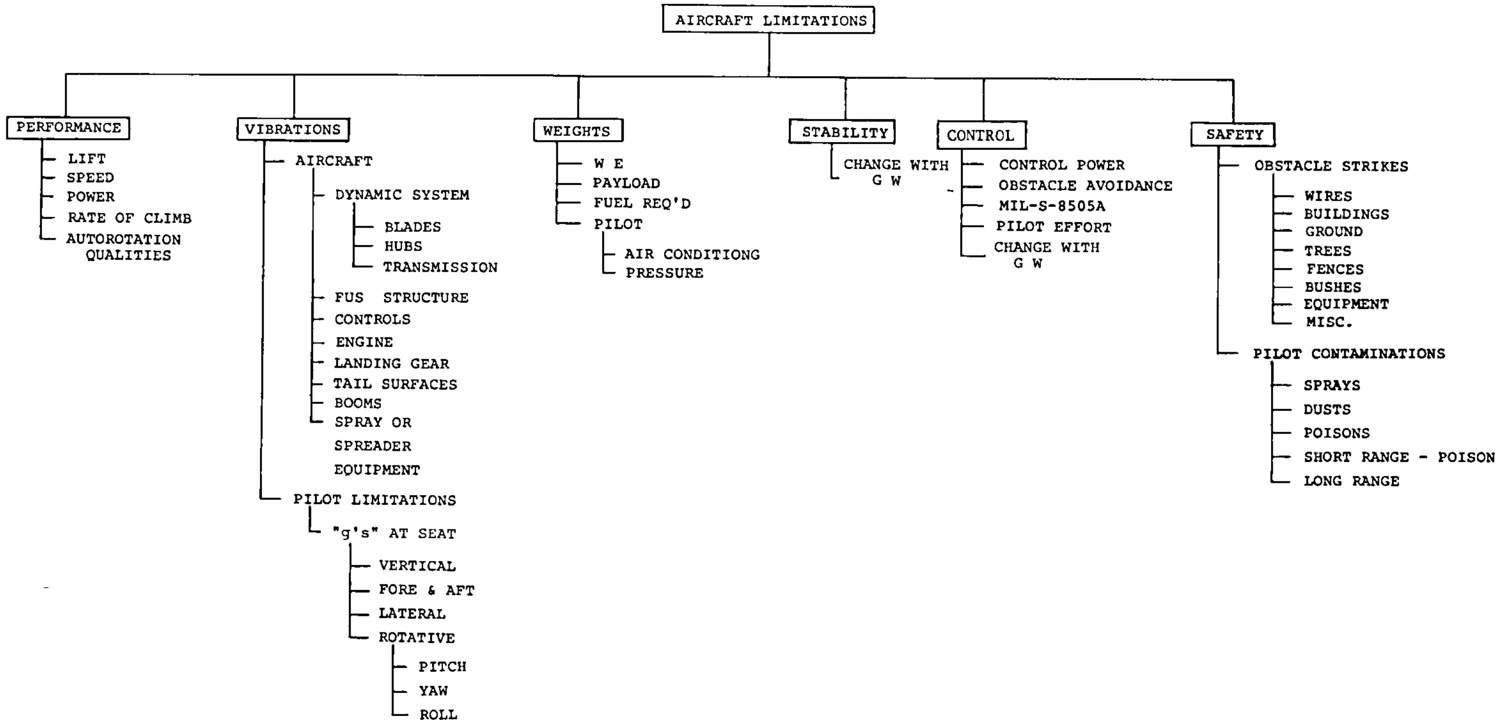


Figure 33. Aircraft limitations.

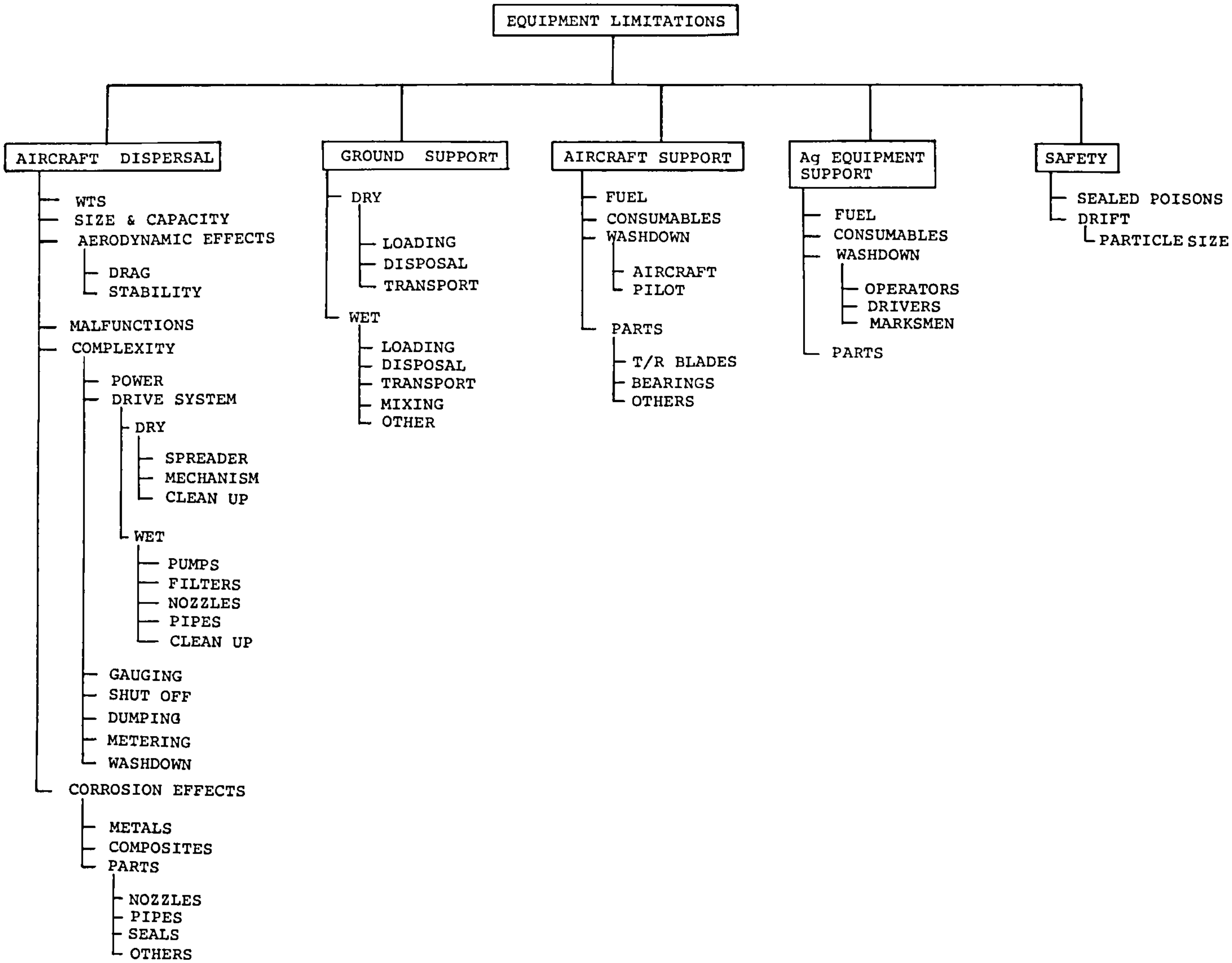


Figure 34. Equipment limitations.

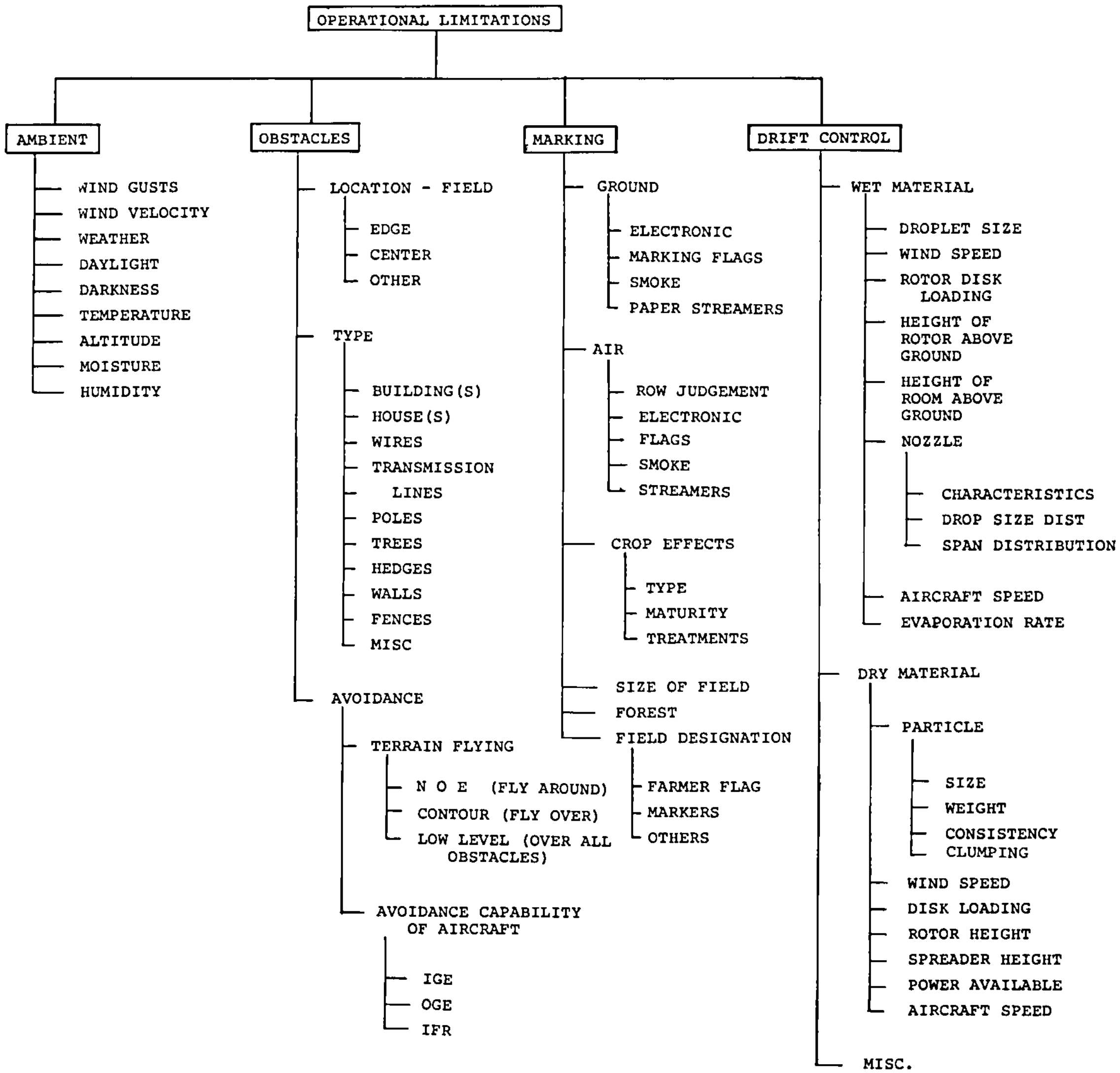


Figure 35. Operational constraints.

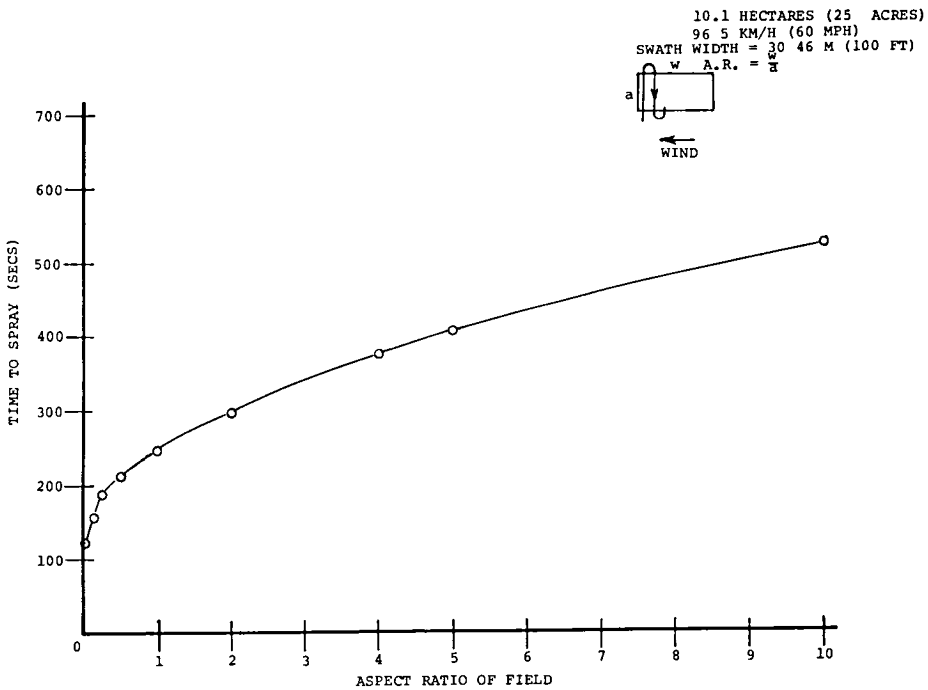


Figure 36. Effect of turns on spray time.

5. MISSION REVIEW EVALUATION

A review of typical operations of small 10.1 hectares (25 acres), medium 20.2 hectares (50 acres), and large 80.8 hectares (200+ acres) field sizes has been made through discussions with operators and owners of Ag material application companies, equipment manufacturers, and involved pilots. A typical day of operations has been evolved for field locations, ferrying distance, and other factors such as shape and distance for a one-aircraft/one-truck team for these three field sizes. Data to establish duty cycles for a typical work day are as follows:

Modes of Operation:

Operator "A" - Fixed base, truck support

Six-month growing season - East Coast

Average size field = 10.1 hectares (25 acres)

80.8 to 200.2 hectares (300 to 500 acres/day) treated/aircraft

Radius of operation = 46.5 km (75 mi)

Type of terrain = hilly, rolling countryside

Altitude range: S.L. to 984.25m (3000 ft)

Wet and dry dispersal

Equipment:

	No.
BHT Model 206	1
BHT Model 47	4
Enstrom	1

Crop Control	Application Rate
Herbicides	1 - 6 gal/acre
Insecticides	1 - 6 gal/acre
Fertilizer	2 - 5 lb/acre
Seeding	As required

Average Flight Time - 2 to 3 hr/working day/aircraft

Operator "B" - Fixed base, truck support

Twelve-month growing season - West Coast

Average size field = 18.1 hectares (45 acres)
Minimum size field = 4.07 hectares (10 acres)

Radius of operation = 15.53 km (25 miles)

Type of terrain = mostly flat, some mountain

Altitude range: S.L. to 1640.42m (5000 ft)

Wet and dry dispersal

Equipment:

	No.
BHT Model 206	1
BHT Model 47	1
Tomcat	1
Airplanes	2

Crop Control	Application Rate
Herbicides	1 - 6 gal/acre
Insecticides	1 - 6 gal/acre
Fertilizer	2 - 5 lb/acre
Seeding	As required

Average Flight Time - 3 hr/working day/aircraft

Operator "C" - Moving Base, Land on Truck Support

Ten-to-twelve months' growing season, Michigan to Texas, perhaps foreign

Average size field = 80.8 hectares (200 acres)
Maximum size field = 404.7 hectares (1000 acres)

Type of terrain - all types

Altitude range - S.L. to 1968.5m (6000 feet)

Wet and dry dispersal

Equipment:

	No.
BHT Model 206	2
BHT Model 205	1
BHT Model 47	4

Crop Control	Application Rate
Herbicides	1 - 6 gal/acre
Insecticides	1 - 6 gal/acre
Fertilizer	2 - 8 lb/acre
Seeding	As required
Varmint Control	As required
Others	As required

Average flight time = 4 hr/working day/aircraft

6. FUTURE MISSION TRENDS

6.1 TECHNOLOGY LEVELS

A portion of the current technology level of the Ag aerial dispersal systems is based on fixed-wing aircraft and engines evolved many years prior to World War II (Stearman Airplanes and P&W Engines among others) with helicopter technology dating back to the late 1940's (BHT Model 47). Newer fixed-wing aircraft powered by turbines and upgraded piston engines also form a current segment of the market in addition to similarly powered helicopters. The potentials of these current aircraft with standard dispersal equipment are great; however, these also represent obsolesent technologies and many improvements could be incorporated. As an ultimate, a high level of technology such as a computer-controlled flight vehicle with a programmed dispersal system using RPV techniques could be evolved to provide aerial agricultural treatment with automation for both day and night flight. It is questionable that any existing viable Ag operation would demand such an ultimate technology (comparable to moon flight); rather, the nature of the business has tended to perpetuate the lesser technology systems. In this day of supersonic ocean flights, rowboats and dugouts are still often used indicating a proper selection of the most appropriate level of job technology (probably based on cost).

U. S. Farmers, by necessity, have always been cost conscious and unlikely to support an expensive way to solve a problem if a cheaper approach exists. Therefore, any improvements in technology over present levels must have a good payoff in terms of increasing profits and/or providing a needed function (food production increase).

A judgmental selection of methodology will always be the key to the success of future technological approaches.

6.2 PREDICTED MISSION TRENDS

A review of the liquid versus dry mission, low and high volume dispersal, field and forest sizes, as well as the effect of various crop requirements on the aircraft and its associated equipment has been conducted in an effort to predict future trends in mission profiles. It appears that future mission profiles may be viewed in parts as follows:

- A continuation of the current modes of operations (same mission profiles) with piston-engine helicopters treating the fields

- An expansion of operations by turbine helicopters through better ground and aircraft support and material dispensing equipment, plus improved techniques. Field shapes, locations, and sizes that are uneconomical or untreatable by airplanes are expected to be increasingly attended by helicopters with improved marking equipment and heads-up displays. New mission profiles will thus be evolved based on these specific improvements. Some general rules for such operations have been reviewed as a portion of this study.

- Use of specials (piston- and turbine-powered aircraft) with borrowed dynamic components such as those either presently flying or under construction. As these aircraft offer increases in payload capacity at a lower operating cost, expansion of the mission profiles could occur. Competition with the airplane where ferry distances are a factor will expand the use of the helicopter as short or nonexistent ferrying occurs with the truck/helicopter team. It could be expected that the introduction of these vehicles would extend the sizes of fields to be treated through their improved duty cycles.

- Design of agricultural helicopters, for a particular purpose, based on newly designed components which are not tied to utility aircraft requirements. Such designs again offer expanded area coverage for the same cost.

- Future problems for the Ag operator will occur from national, state, and local governments, as well as with environmental groups with various agencies on all levels creating serious changes in operational modes, types of apparatus, chemicals permitted, and the business climate. Future hardware will reflect this, and the legal penalties occuring for operation must be avoided by new design technology developments. Mandatory accurate drift and dispersal control will provide significant improvements in Ag applications. Reduction of the loss of fines could be expected to increase the effective spray load carried by as much as 30 percent and thus permit expanded mission profiles (work coverage/flight) for a particular aircraft.

7. METHODS OF INCREASING AG AIRCRAFT PRODUCTIVITY

7.1 INTRODUCTION

7.1.1 General Design Criteria for System

Development criteria are in order to establish practical aircraft and dispersal and ground service systems for review. Basic are general factors such as the following:

- Acceptable functioning of the system; i.e., conformance to operational requirements and specifications
- Minimum weight and aerodynamic penalties for the associated systems
- A reasonable expenditure to perform the function including design, development, test, and production costs
- Other characteristics are prime such as the following:
    - Low complexity
    - Good maintainability and service life
    - High reliability
    - Efficient duty-cycle time
    - Low system weight
    - Pilot acceptability
    - Transportability (ground and air)
    - Low noise
    - High visibility (operational signature)
    - Low fire hazard
    - Agility
    - Reasonable power requirements
    - Safety
    - Acceptability for use by field personnel
    - Controllability, with and without load

From the above, specific criteria relating to the aircraft, its equipment, and the ground handling system may be delineated.

7.1.2 Specific Criteria for Ag Aircraft

Desirable criteria for agricultural aircraft may be noted as the following:

- High payload/gross weight ratios, i.e., low-weight empty fractions

- Cruise speeds up to 100 mph
- Good stability and controllability
- Unrestricted forward, side, and down vision with a clear view of the boom, nozzles, and spray apparatus
- Impact resistance for wire or obstacle strikes such as a bendable boom and crashworthy design
- Dust and vapor-proof cockpits with air conditioning and pressurizing. Easy transparency cleaning for visibility
- Easy aircraft inspection and maintenance (swingout engines)
- Bearing-free, noncorrosive-type structures for dynamic parts, as permissible
- Simple aircraft and equipment designs with readily replaceable components
- Reliable inexpensive engine(s) with simple parts (present production-type aircraft or automotive). Low price turbine when available
- Low vibration levels on pilot
- Easy loading of aircraft for fuel, oil, and dispersed materials
- Size determined by use, i.e., fertilizer may need bigger vehicle than spraying

The above criteria may be translated into detailed overall favorable features for new aircraft designs as indicated in the following section.

Some of the design features to fulfill the Ag need are as follows (reference Figure 44):

Structure:

- Simple structure
- Composite and/or machine produced
- Crashworthy cage
- Direct load paths - few bulkheads
- Isolated engine/drive train
- Integral fuel tanks - crash sealed
- Easy part replacement - exterior attachment

- Pressurized cabin - Cantenary-blown plexiglass or polycarbonate
- Airconditioned cabin
- Isolated pilot, instruments, controls, four-bar linkage
- Spring-leg landing gear - equal struts
- Fiberglass skids - strike protection

Transmission:

- Single-main reduction gearing
- Isolated transmission gearboxes
- Supercritical tail rotor shafting
- Constant-speed couplings
- Main gearbox
    - Five-bevel gears
    - One auxiliary drive from ring gear
    - Six takeoff pads
    - Bearings - preloaded
- Large diameter rotor shaft - Integral hub
- Centrifugal clutch/free-wheeling unit
- Tail rotor gearbox
    - Two bevel gears
    - Bearings - preloaded

Controls:

- Main Rotor
    - Dual boost - fail-safe internal mast - stationary control
    - Top of hub swashplate
        - Collective - up and down motion
        - Cyclic - swashplate tilt
    - Tail Rotor
        - Single boost - fail-safe internal mast

Stability Devices

- Controlled Stability - damping/sensing device on rotor shaft/tip path plane motion

Rotor Design

- Main Rotor: Two Blades - Infinite Life

  - Bearingless hub design
  - Strap retention of blades
  - Composite blades
  - High energy
  - Reduced rotative speed where applicable

- Tail Rotor - Two or Four Blades - Infinite Life

  - Shrouded low aspect ratio blades
  - Combined shroud and horizontal surface
  - Composite blades
  - High energy
  - Sound controlled (Low acoustic signature)

Power Plant

- Engine

- Piston Engine

  - Liquid or air-cooled
  - Aircraft or converted automotive
  - Exhaust ejector cooling aid/muffler
  - Fan cooling of engine and oil

- Reduced price turbine(s)

Equipment

- Spraying

  - Tank - Fiberglass
  - Hydraulic pump drive - transmission takeoff
  - Boom - Folding, controlled droplet size and patterns - drift-control tip jets - location out of downwash in view of pilot
  - Radio communication aircraft/truck

Instrumentation:

- Spray Equipment
- Engine
- Rotor   Monitoring
- Flight
- Flow control - spray
- Emergency/safety
- Heads-up display

7.1.3 Operational Criteria

Rules for Missions

- Select nearest field for first treatment
- Select lowest altitude field first if staging point is at a lower altitude
- Select highest altitude field first if staging point is at higher altitude
- Work downwind fields first
- No marking system for fields under 60 acres or for row crops
- Number of aircraft available

  One
  Two
  Many

- Specify swath length, width, shape of field; i.e., square, rhombus, rectangle, others.
- Staging area locations

  Mobile trucks - working from base

- Wind direction and magnitude(s)
- Initial pass to define obstacles (perimeter and diagonal)
- Obstacles - Types

  Hills, trees, homes, structures, wires, poles, transmission lines

- Select field passes to minimize number of turns

7.2 DESIGN CONFIGURATIONS

7.2.1 Aircraft Possibilities

Figure 37 is a morphological chart of possible aircraft design concepts that may be used for Ag purposes. These range from utility types with retrofit kits through Ag specials with dynamic components from existing aircraft, as well as completely new designs. Figures 38 through 40 show contemporary aircraft in utility configurations as might be used for Ag purposes to the year 1985 and beyond. Synthesized aircraft of

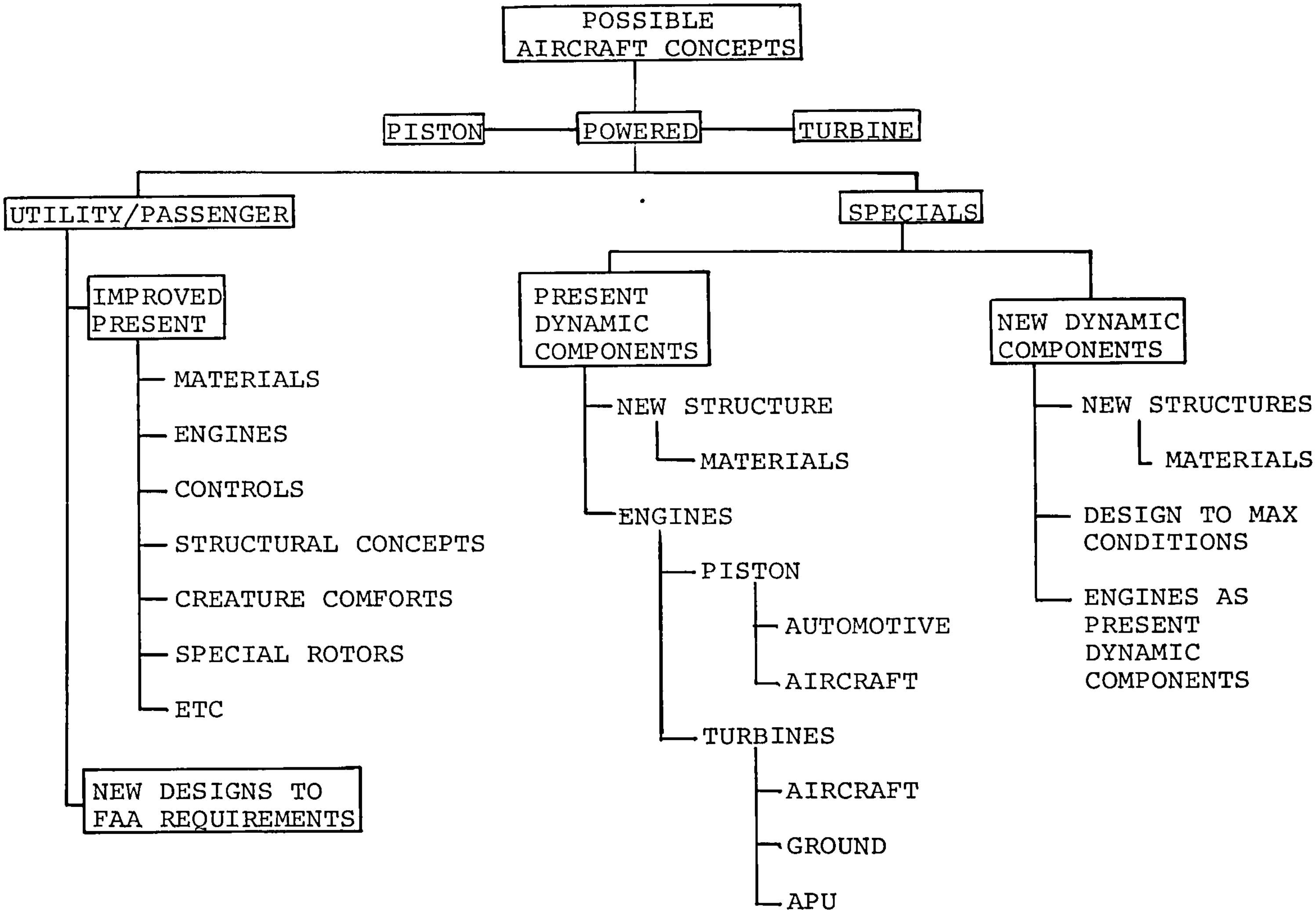


Figure 37. Types of possible Ag helicopters.

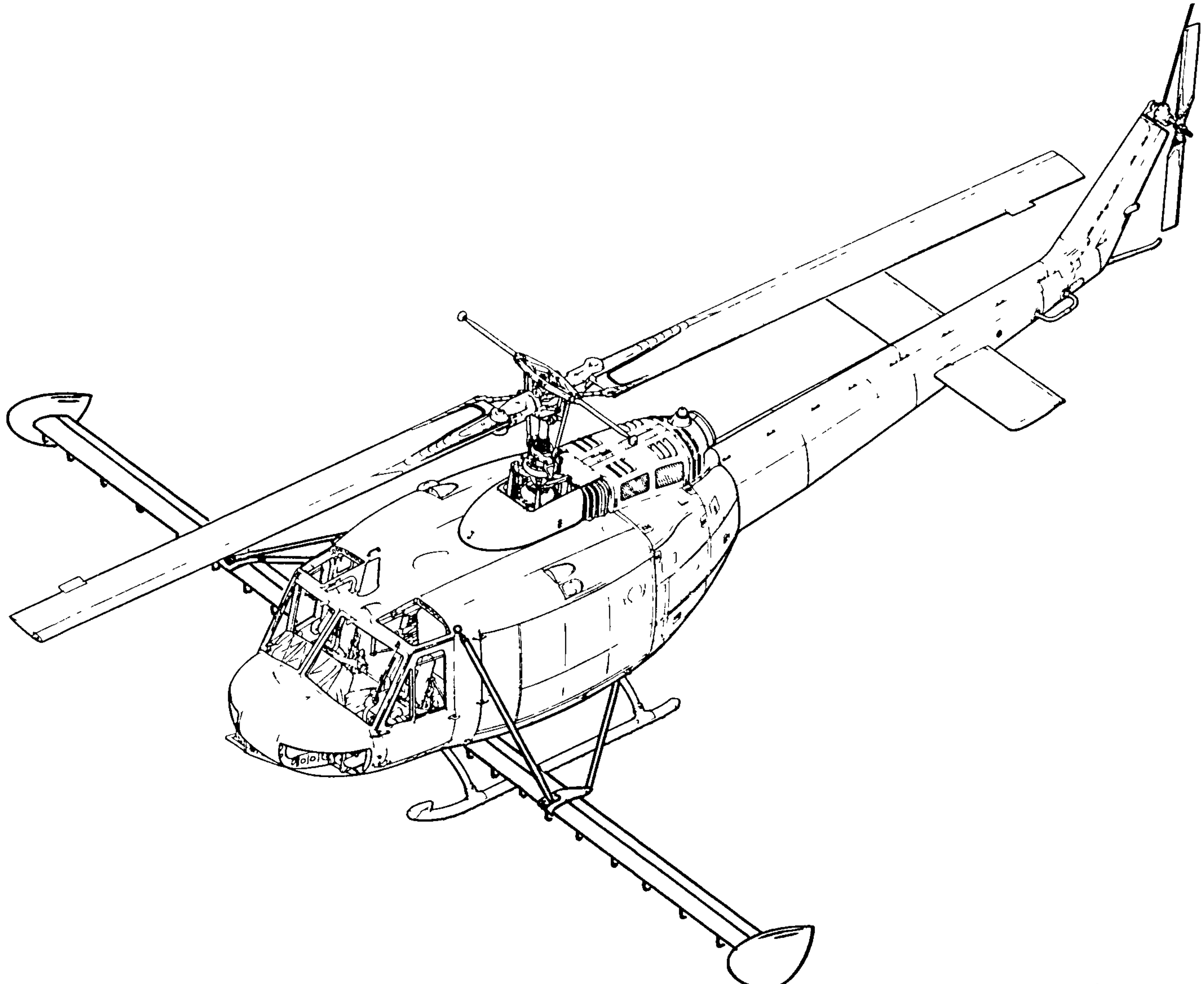


Figure 38. BHT Model 205 with tip control curtain boom - interior tanks.

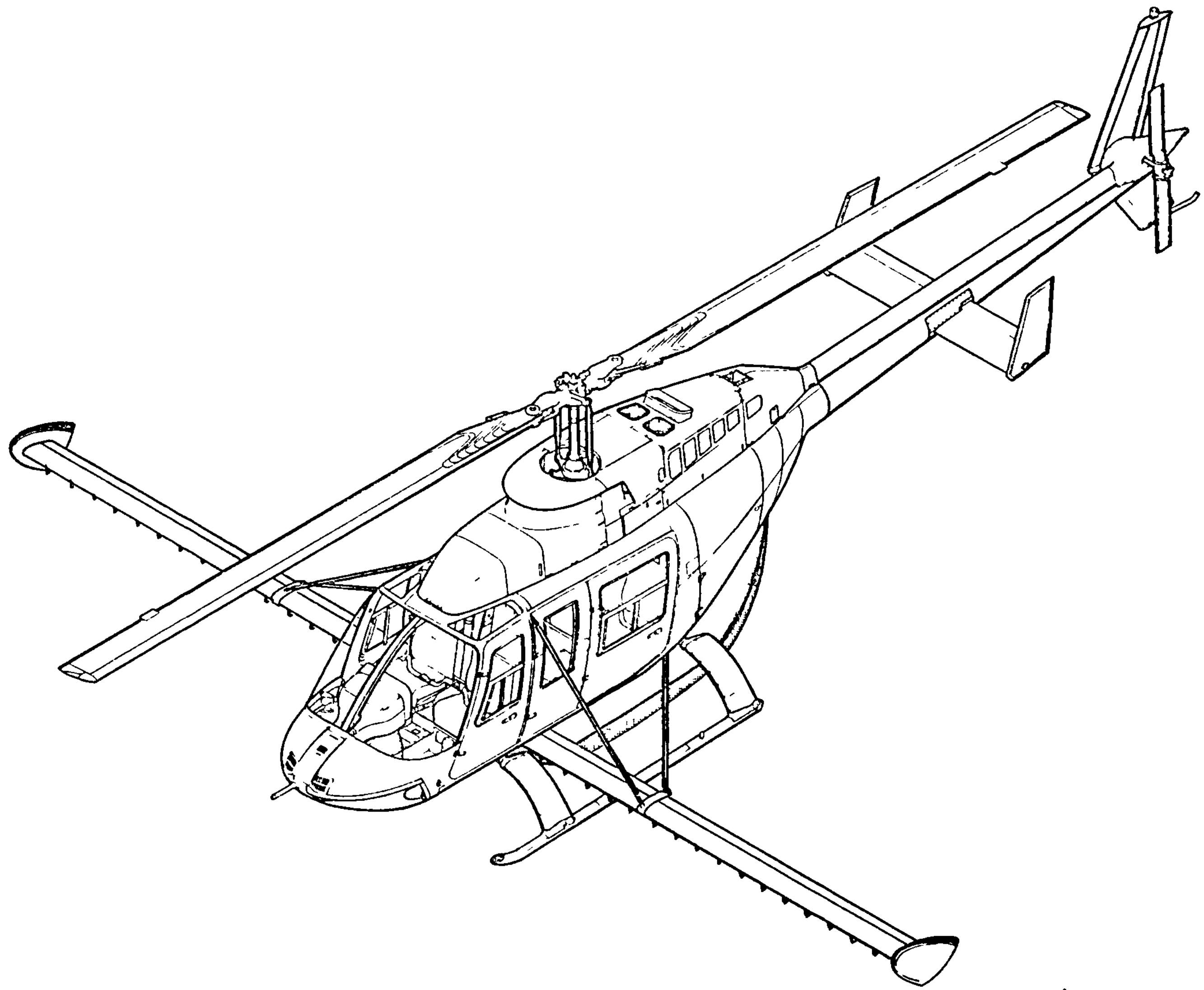


Figure 39. BHT Model 206 with tip control curtain boom - exterior tanks.

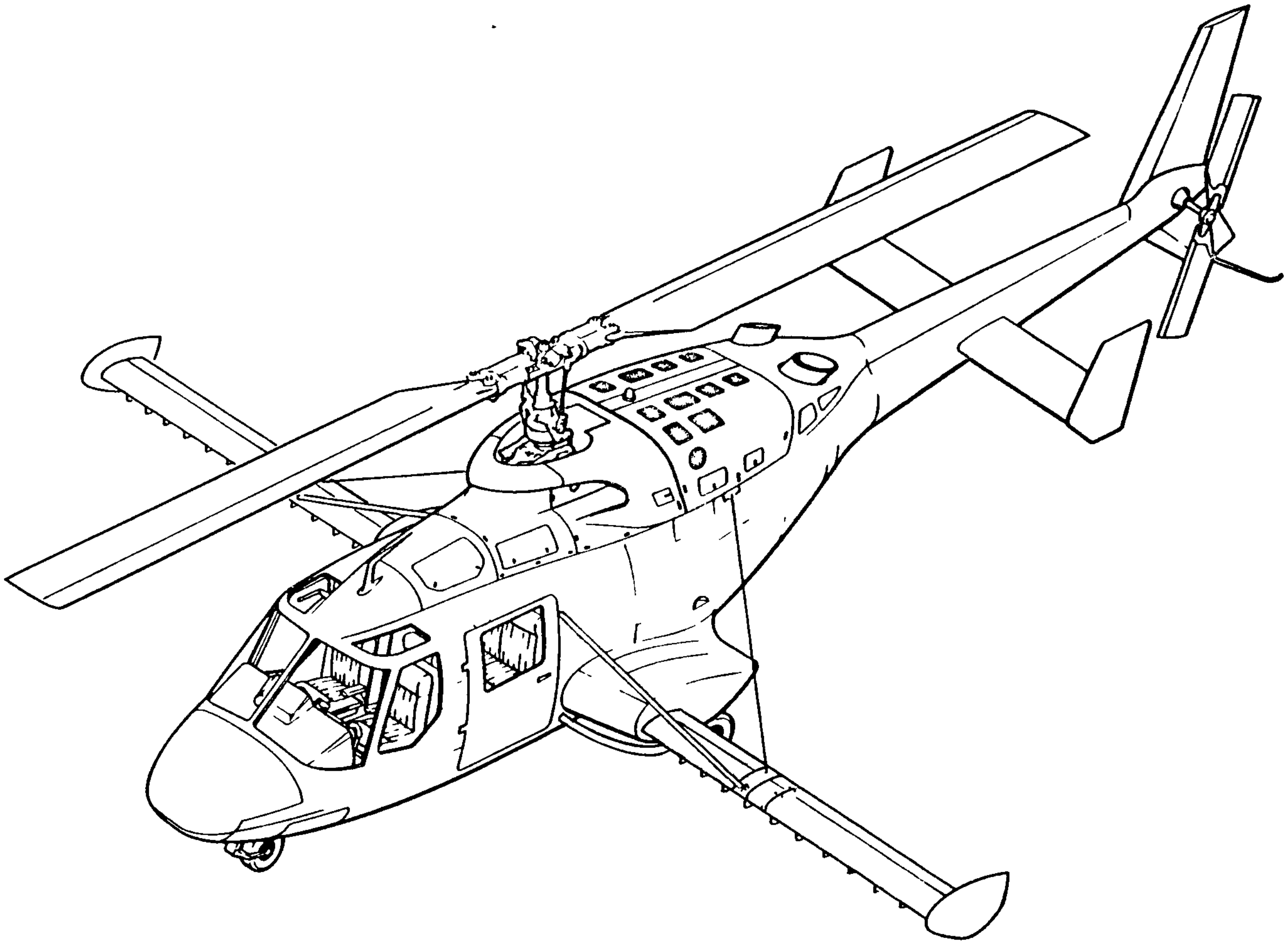


Figure 40. BHT Model 222 with tip control curtain boom - interior tanks.

different gross weights from the models indicated in these figures were used in this study. However, BHT weights methodology, as utilized in proportioning current aircraft, form a part of the synthesis program.

Figures 41 and 42 show Ag specials based on several BHT aircraft dynamic components; specific data on these vehicles are tabulated in Appendix D. These vehicles are examples to be analyzed for various technological level effects in Section 8 of this study.

Figure 43 denotes the parametric variations used in current Ag helicopters, i.e., power loading in kg/kw (lb/HP) and disk loading in kg/m^2 (lb/sq ft) versus gross weight in pounds for both piston- and turbine-powered aircraft. These data indicate lower power loadings and higher disk loadings for the turbine-type aircraft which reflects the power/weight advantages of such propulsion. Data from Figure 43 were used to indicate the design configuration aircraft of Table 8. Figure 44 aircraft is representative of this class and provides desirable features of safety and operation as indicated in Section 7.3.

One problem encountered in the layout of an Ag helicopter design is determining the location of the spray boom. Figure 45 is a definition of the wake angle and downward wind velocity versus the forward speed in km/hr (mph). The boom should be located outside this wake for a minimum distrubance of the spray pattern. Special considerations in locating the boom for lofted wakes are noted in Section 7.3.11.5.

7.3 PROPOSED CONCEPTS TO INCREASE PRODUCTIVITY

7.3.1 Introduction

Techniques for increasing productivity of the Ag aerial dispersal system may be related to all of the elements of the system (reference Figure 2) with general application as follows:

Aircraft

- Improvements in structural weights, i.e., through new material uses (composites, exotic metals, etc.), new structural concepts, or more effective application of existing materials.

- Use of better engines (increased power for the same weight). Power plant failure is one of the prime causes of accidents (reference Section 1.); therefore, significant engine reliability and safety improvements are required. This has been achieved by aircraft in the past by three general approaches:

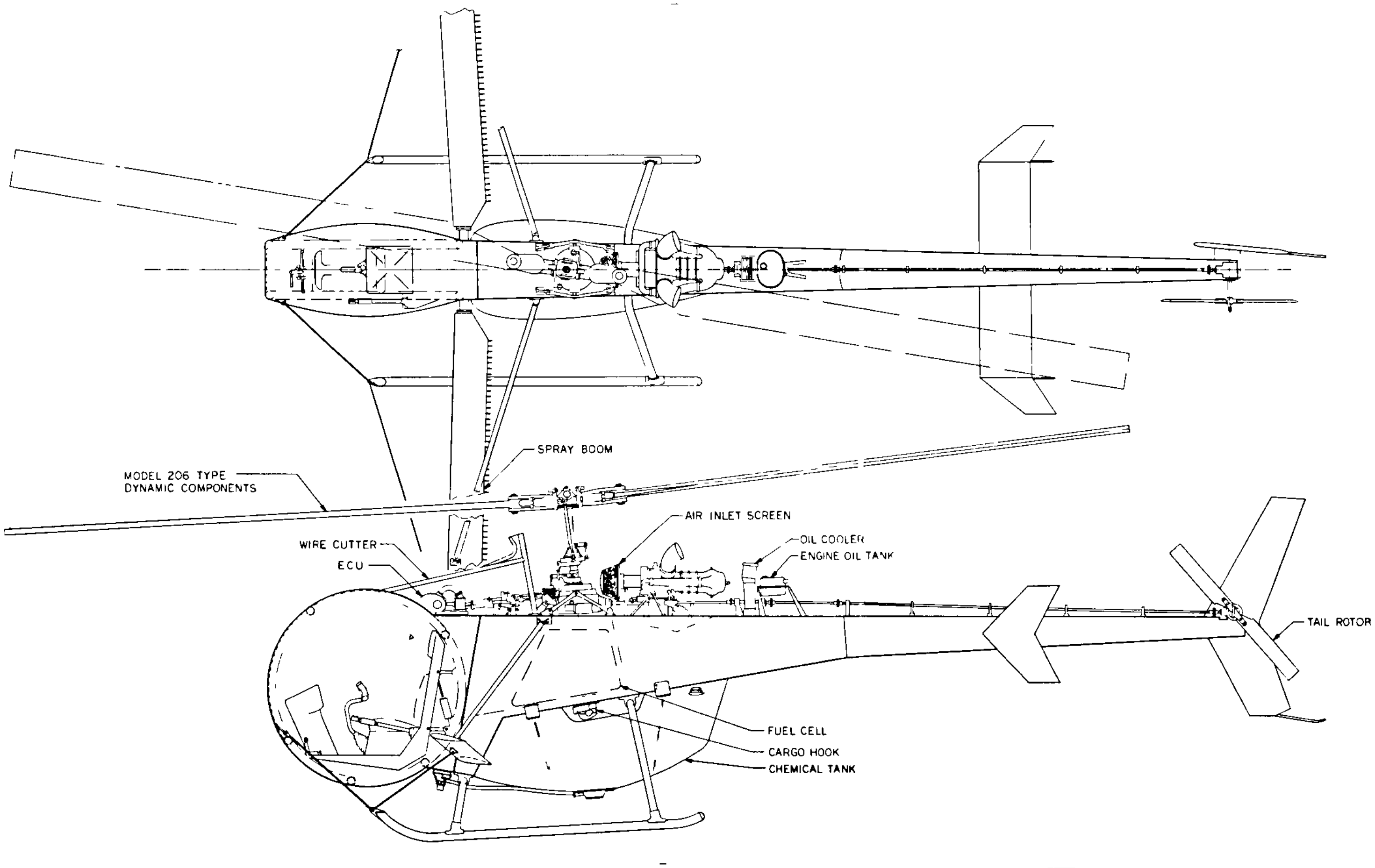


Figure 41. Ag special with Model 206 component.

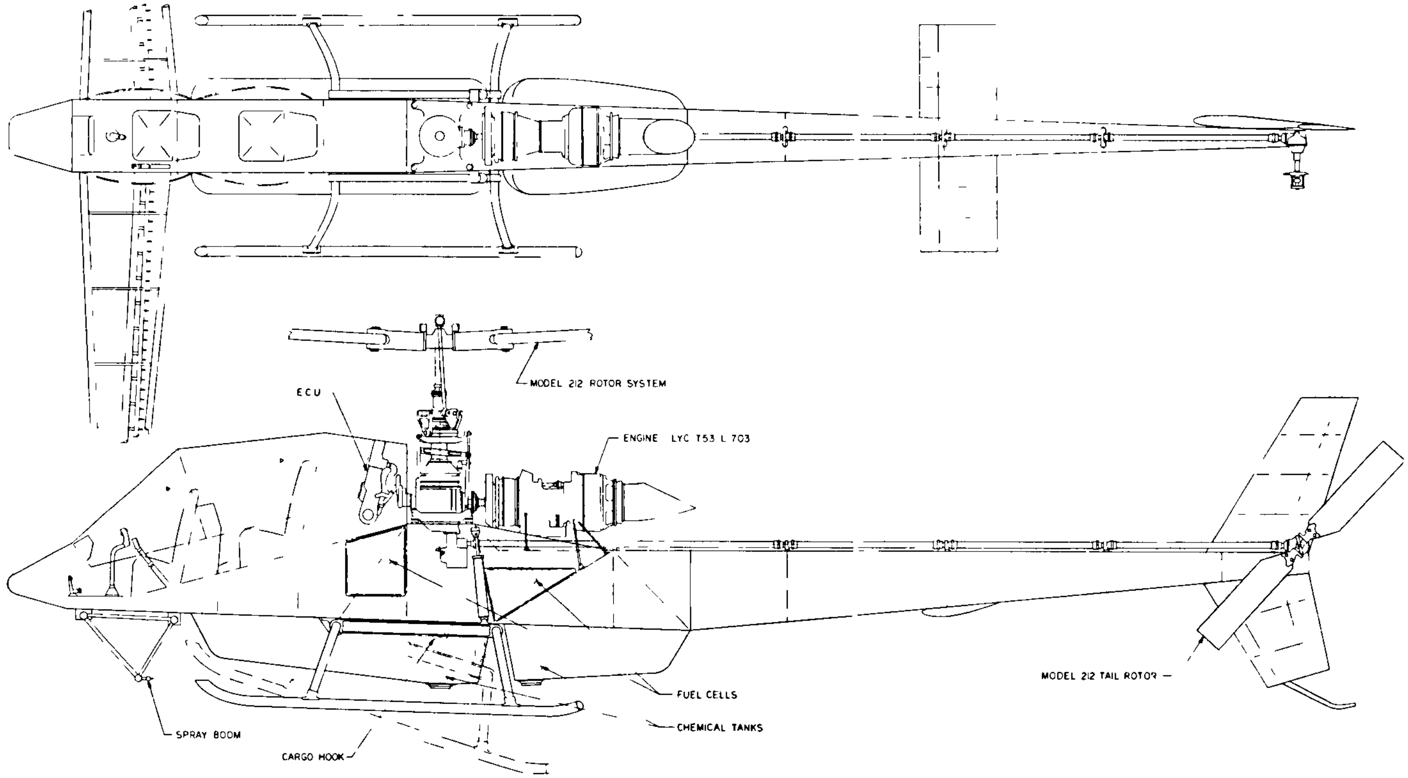
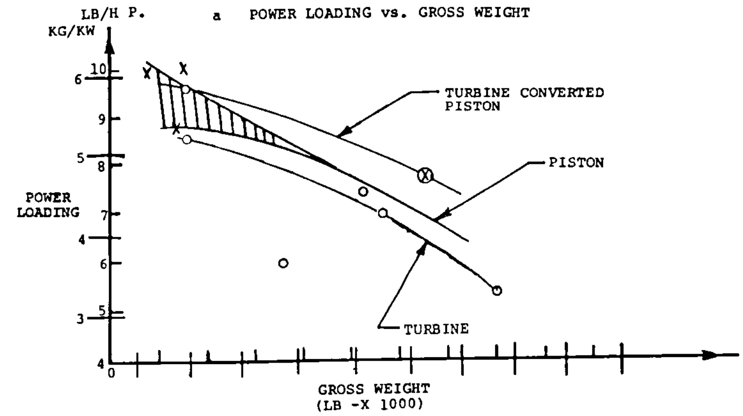


Figure 42. Ag special with Cobra components.



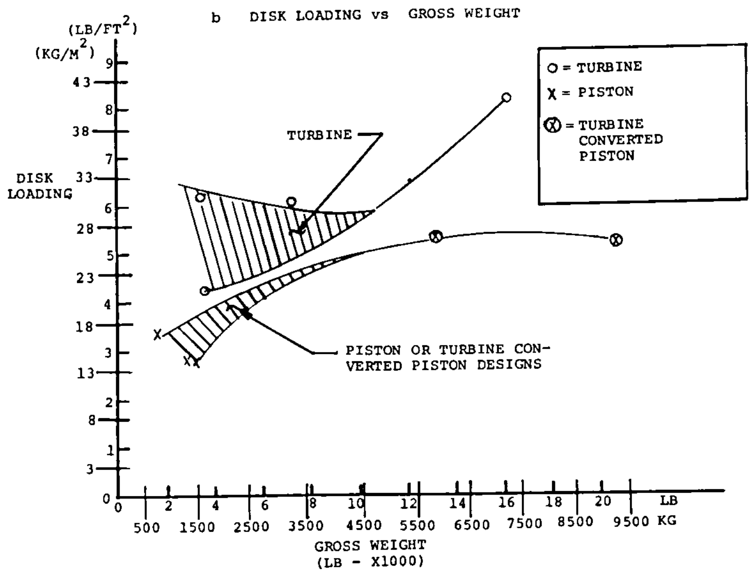
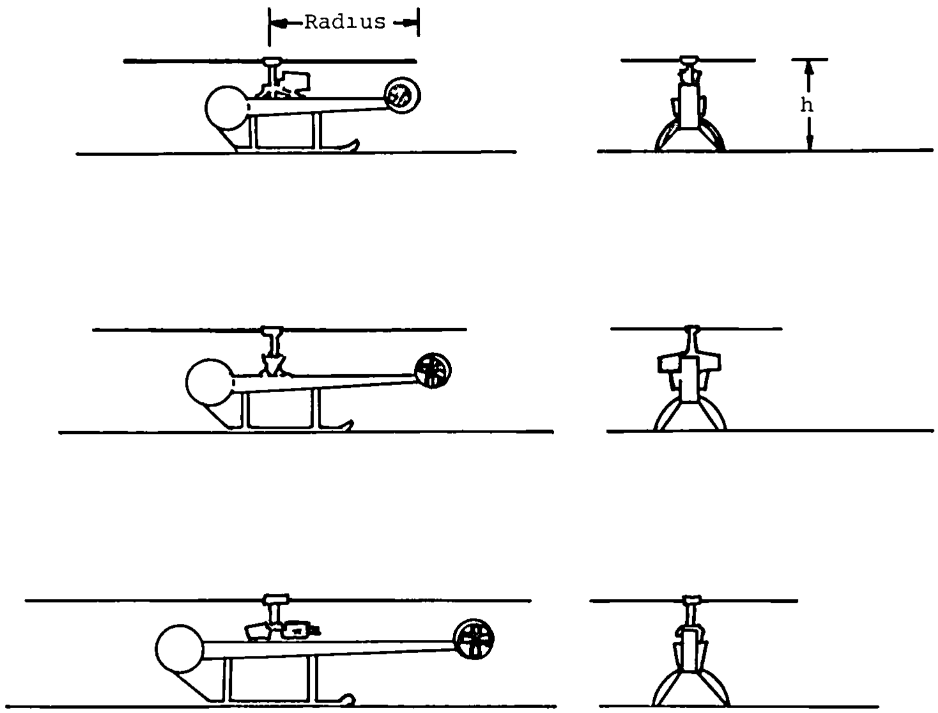


Figure 43. Ag helicopter parameters.

TABLE 8. DESIGN CONFIGURATIONS

Model	Gross Weight	Disc Loading	Power Loading	Radius	h	Horse Power
Special Piston						
ASP	3000	3.5	9.3	16.8	10	322
BSP	6000	4.4	8.2	20.8	11	731
CSP	12000	5.1	7.4	27.3	12	1620
Special Turbine						
AST	3000	4.9	8.5	13.5	10	353
BST	6000	5.2	8.3	19.1	11	725
CST	12000	6.7	6.8	23.8	12	1760

A, B, and C = Gross Weight
S = Special
P = Piston
T = Turbine
U = Utility



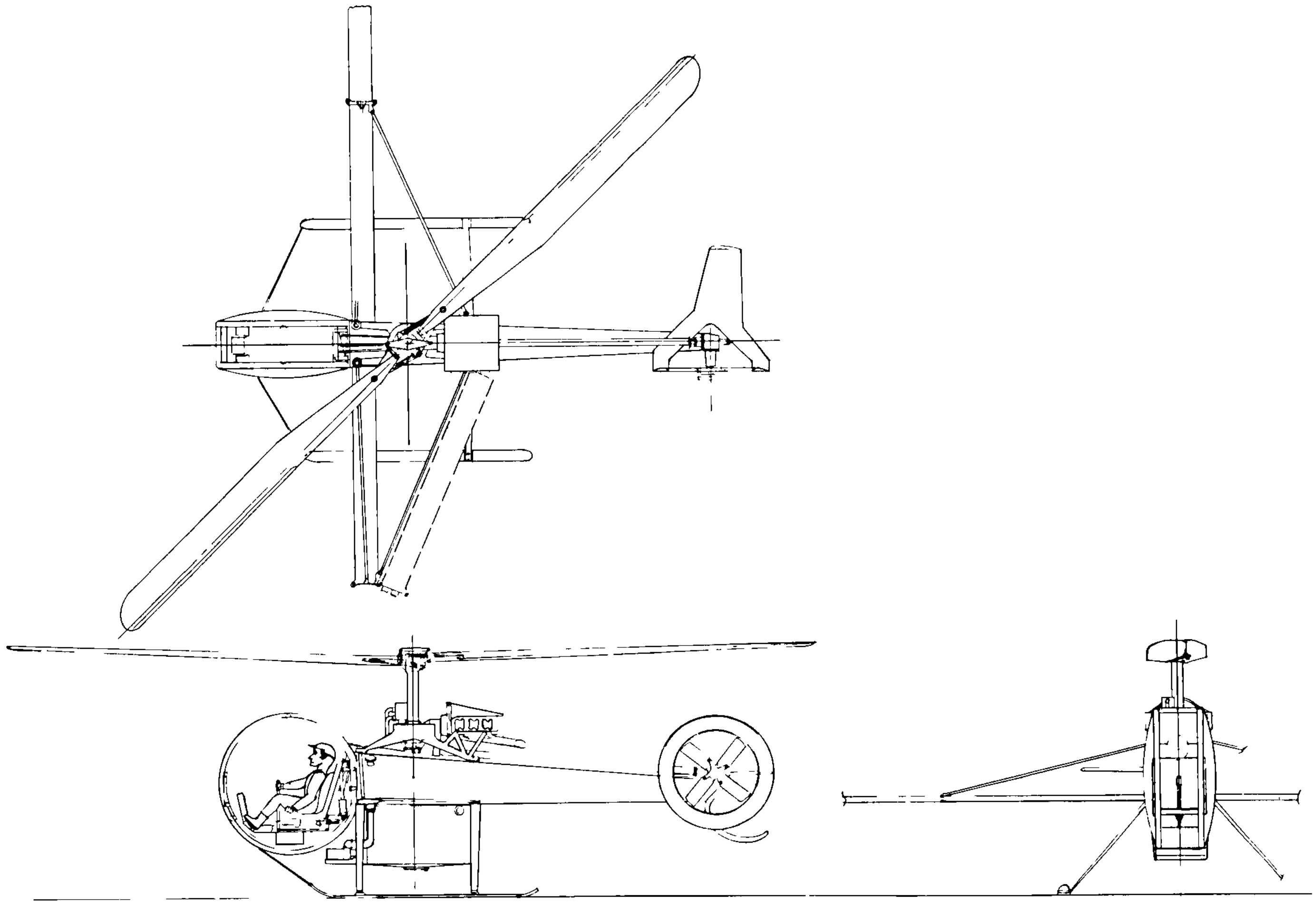


Figure 44. Ag special new components.

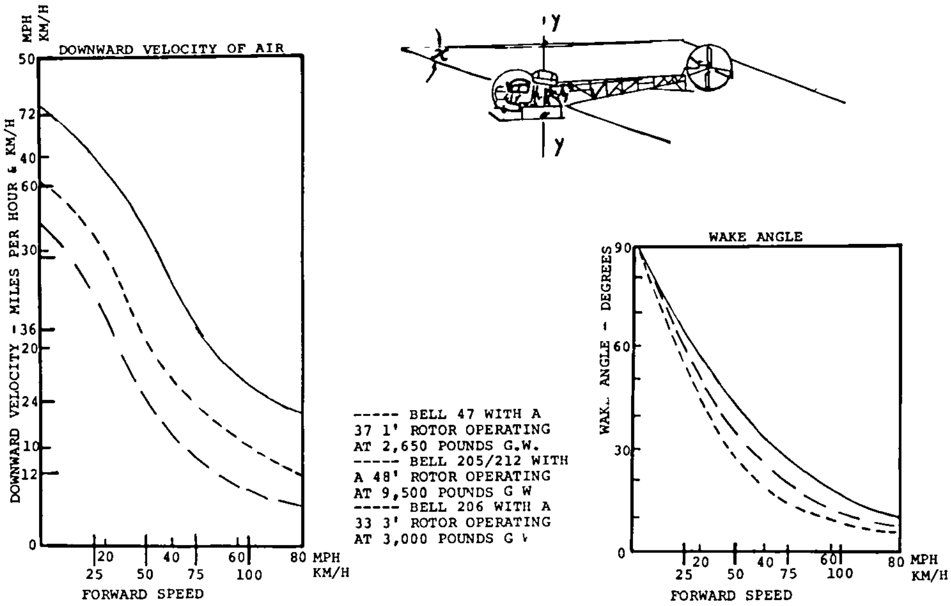


Figure 45. Selection of boom location.

- By redundant use of power plants, i.e., application of two or more engines.

- By the application of a more reliable engine system, i.e., using a proven turbine whose TBO service record betters that of the piston type. Improved fuel consumption in this area is also helpful but not critical.

- Standby temporary power systems such as liquid or solid rockets, gas generators for short term auxiliary turbine use, fly wheels, blade tip ramjets, etc., for flight propulsion in the event of prime mover failure.

- Aerodynamic improvements in rotor system, i.e., specialized rotors to increase rotor L/D ratios or use of the guarded tail rotor to increase thrust without power increase.

- Improved airfoil sections and better tailoring of the rotor system to Ag use, i.e., biasing rotor design parameters to the slower flight speed/higher lift capacities needed for Ag use.

- Use of direct lift, i.e., the application of an auxiliary wing in solids dispersal or conversion of the spray boom to a lifting surface.

- Reduction in drag, i.e., the streamlining of the boom and its attachments, rotor hubs, landing gears, etc.

Creature Comforts

- Although increases in creature comforts (reduction in pilot effort, better stability and controllability, air conditioning, cockpit pressurization, crash protection, good visibility, low vibration, etc.) are not readily quantified in terms of improvements in productivity, less pilot strain and fatigue contribute to a more effective material dispersal through the practical potential for more working hours per day and lower probability of error.

Equipment

- Improvement to dispersal equipment in the form of better system reliability and maintainability will also contribute to increased productivity. Improvements in drift control through nozzle and boom developments (fines control) can be expected to save up to 30 percent of presently wasted dispersed materials, and, timed swath turn on and shut off await the attention of equipment manufacturers for system improvements.

Operational Considerations

- A speed/power polar for the Model 47 is shown in Figure 46, and it may be noted that horizontal flight at translational speed up to about 80 mph usually requires less power than hovering. This relationship has been used for many years as the basis for the takeoff of overloaded helicopters. Once the aircraft is airborne and uses fuel or discharges cargo to reduce flying weight, hovering becomes possible. In the case of air pickup of an extra load (flight refueling, icing, or other), it is possible to safely land the vehicle with a run-on landing to prevent crashing.

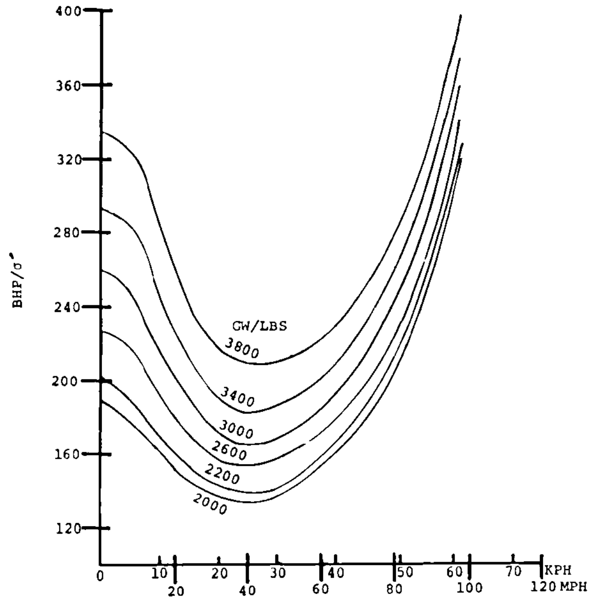


Figure 46. Model 47 helicopter speed - power polar 3200 RPM.

From this, various operational techniques may be used to improve the payload capacity of a particular vehicle as follows:

- Running takeoff to 30 mph to permit reduced power flight; however, Ag operators have indicated that ground areas to permit use of this technique would probably not be available at most Ag fields. Ferrying costs, if using a fixed base, would probably obviate this approach also.

- Launching from a service truck by means of a tiltable ramp. This appeared somewhat more desirable with truck costs being the determining factor.

- Launching from a service truck platform with the truck moving at 30 mph. This appeared feasible in that most fields have bordering roads suitable for these speeds. Special equipment to hold the aircraft before release would be in order.

- High inertia rotors or flywheel systems may be used for jump takeoffs.

- Auxiliary intermittent power-boost blade tip rockets (liquid), ramjets, JATO, gas generators, etc., for liftoff.

- Catapult launcher from a truck is another possibility, but the cost of acquisition and operation of such a device tends to preclude its use.

- Short-time increased power outputs (2 to 2-1/2-minute ratings) may also be used to increase payloads.

- Aircraft handling qualities and reduced available load factors at these overload conditions (GW = 1.3 x normal GW) are possible problem areas. FAA certificated levels for gross weight and load factors need to be reviewed. Perhaps "g" and weight recorders to indicate aircraft history would be useful in determining any fatigue damage (reference Section 7.3.5).

7.3.2 Factors Considered in Analysis

In order to manipulate the helicopter synthesis computer program, various factors to modify inputs to reflect changing conditions were used. These factors listed in this section were based on discussions with BHT experts in particular fields, literature searches, and judgmental opinions. Some of the considerations relating to these choices are reviewed in the following sections (7.3.2 through 7.3.15) of this report.

- Materials Variations and Structural Concepts

  - Fuselage - 90 percent of standard weights
    - Specials - 50 percent of standard weights through use of composite materials
  - Transmission - 80 percent of standard weights through use of composites
  - Rotors - No change for structure
  - Landing Gear - 80 percent of normal weights through use of composites
  - Controls - 80 percent of normal weights through use of composites

- Booms, tanks, and equipment system weights are a percentage of their carrying capacity (Reference Figure 24)

- Crashworthiness - 3 percent structural increase

- Power Plants

  - Aircraft piston 224-374 Kw (300-500 hp)

    - Installed weight = 1.6 lb/hp

    - Fuel consumption = .048 - .052 lb/hp/hr

  - Automotive conversions

    - Installed weight = 2.2 lb/hp

    - Fuel consumption = .052 - .056 lb/hp/hr

  - Aircraft Turbines

    - Installed weight = as normal .35 - .5 lb/hp

    - Fuel consumption = 8 percent improvement by 1985

- Stability and Controls - standard factors

- IGE Flight Effects (reference Section 7.3.6)

- Specialized Rotors

  - High energy rotor - main and tail rotors

    - Assume 25 percent weight increase of rotor systems

  - Slowed rotor - 90 percent, 80 percent, and 70 percent of normal rotor rpm

- Creature Comfort

  - Pilot effort reduction

    - Normal controls values

    - Inplane counterweight systems

      Tail rotor - 5 percent tail rotor weight

      Main rotor - 5 percent main rotor weight

- Cockpit environment
  - Pressurization - 20 lb/aircraft
  - Air conditioning - weight = 55 lb
    $1495 plus installation

    Power = 4 hp

    Weight = 80 lb
    $2000 plus installation
- Crash protection - see Structural
- Fire protection - 1 percent engine installation weight
- Pesticide avoidance (engine, compressor intake filter)
  - 1 percent engine installation weight
- Visibility - windshield washer and wiper - 1 percent dry engine weight
- Vibration isolation - 4 percent of fuselage weight

- Operational Consideration
  - Direct lift - 5, 10, and 15 percent of gross weight
    - Lifting boom assumed
  - Drag - boom and tank drag
    - Parasite
    - Drag due to lift from boom

      Boom L/D ratio = 10
  - Side force controls - adjustable fins on booms
    - Weight = 8 percent Fuselage

- Environmental Considerations

  Engine Noise - muffler/ejector - 10 percent engine weight

- Main Rotor - low rpm - 25 percent weight increase

- Pollution - engine fuel control - normal plus lean burn - 2 percent engine weight

  - Exhaust treatment - compressor bleed air burn - 5 percent engine power penalty

  - Auxiliary compressor ejector

    5 hp weight = 40 lb

- High Lift Systems and Effect on Material Distribution Not Applicable

- Flight Path Control Without Pitch Attitude Change - Rotor/Fuselage Flight Path Automatic Trim Device with Collective Change - Weight Estimate = 100 lb

7.3.3 Materials

Current methodology for the improvement of aircraft equipment and systems is based on increasing use of composite materials. Large monies have been spent to date by the U.S. Government as well as industry for evaluation, test, and production of such composites for aircraft uses. Composites have the uniqueness of providing a means of designing material characteristics to the requirements of a particular geometrical strength situation through fiber orientation and choice of matrix. Unfortunately, a problem exists for Ag use in that one of the prime characteristics of chemical sprays and fertilizers is a high corrosive effect. Tanks used to contain these elements have been fabricated from aluminum, carbon and stainless steel, composites, and other materials. Examples of such tanks being destroyed by corrosion in very short times exist, i.e., fiberglass tanks have "washed out" in less than two months service; conventional aircraft paints on the fabric exterior of an Ag machine under such conditions may last less than a year. It is apparent that any possible improvements in the corrosive-resistance abilities of composites or other materials will thus be beneficial in increasing their application for Ag use.

Normally, substituting composites for metal in aircraft primary structures offers a weight advantage when a support structure (by design or configuration) is provided in order to make panel buckling or other deflections a noncritical design factor. If strength characteristics of composites tend to deteriorate under such corrosive conditions, any structural advantage is lost; washdown and flushout of the structure thus becomes mandatory with drainage most important.

For the purpose of this study, it is assumed that by 1985 composites in helicopter structure will have improved to the point that a 10 percent structural weight reduction will occur for fuselages of utility helicopters, and a 50 percent weight reduction for the "specials."

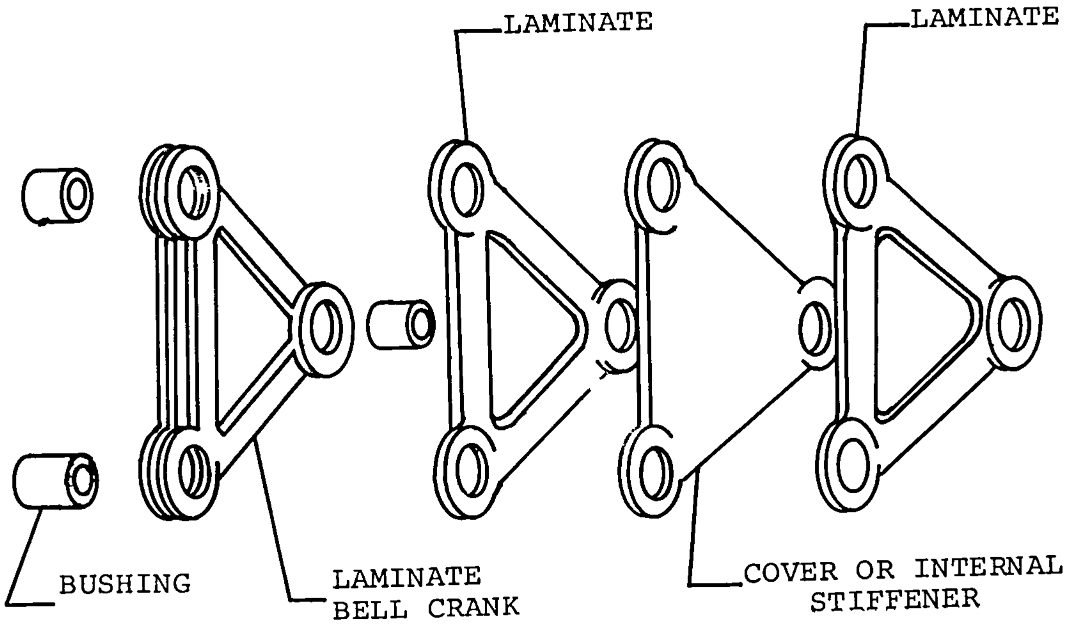
Composite transmission parts (drive shafts, gearboxes, couplings, bearing housings, etc.) are expected to weigh 20 percent less than current types. Landing gears and controls are expected to encounter similar reductions.

7.3.4 Structural

Structural improvements to increase the productivity of the Ag system mainly relate to the aircraft and its equipment rather than to the ground portion of the system; however, lightweight ground equipment could offer advantages where manpower is used to move or handle materials. Also, other considerations such as cost, availability, corrosion resistance requirements, etc., have limited the use of fiberglass helicopter helipad/ tank trucks, loaders, and the like.

Perhaps the best overall structural improvement to Ag helicopters and airborne equipment would be the expansion of the use of defect-tolerant structure, i.e., fail-safe, safe crack-growth, or crack nonpropagating types. This presents a means of providing safety and corrosion control (operator ranked ninth at .62 in Section 1) for various portions of the helicopter structure. This is achieved by providing dual or multiple load paths for critical components (rotors, transmissions, controls, landing gears) with indicating devices to register partial failure (pressure loss, electrical conductivity change, ultrasonic registry change, etc). In addition, the use of crack-stopping design and nonpropagating materials (where applicable) are required.

Reference 8 describes the application of this philosophy to the helicopter rotor system and controls; however, fail-safe design, although more costly, has been a requirement for U.S. transport airplanes for many years and, consequently, catastrophic accidents due to structural failures of wing and tail surfaces are nearly unknown in the airline business. Reference 8 shows also that including the defect-tolerant provision is often not a weight adding procedure. This philosophy is not only for major component treatment such as double (inside/ outside) blade retention pins but should be applied to most primary component detail design. For example, instead of a control horn being made from a one-piece metal forging, it could be fabricated from bonded laminates (reference Figure 47). The bond lines act as crack stoppers, the material could be distributed in a most favorable manner, and a reduction in weight may thus be possible. Intermixing of laminates of metal (steel, aluminum, titanium, beryllium) and composites could permit superior strength and lighter weight structural parts.



1. Stamped from sheet (laminated steel, aluminum, bonding materials, et al.)
2. Turned bushings (bonded with laminates into an assembly)
3. Bearings roll staked at pivot points

Figure 47. Bonded laminates vs solid forgings.

Corrosion or weathering effects on composites rapidly reduce allowable strengths in fatigue (Reference 9), and it appears that multiple load paths and types of noncrack propagating materials used on critical items could be a most effective measure to improve the Ag aircraft and its equipment. From the survey of Section 1, where the reliability of helicopter power plants is stated as operator concern, with the accident rate bearing out this factor, a question arises. Why do Ag operators of both fixed and rotary wing aircraft have this problem? Perhaps it indicates a lack of adequate maintenance (cutting corners) based on the factors of obsolescent engines and aircraft parts unobtainable at any price plus the addition of high maintenance costs. If such is the case, maintenance on other components is also reasonably likely to be minimal; therefore, defect-tolerant components may become important in providing a safety solution for this problem. Failure in fatigue of two structurally parallel infinite life parts, where one is unloaded until failure of the other, is most unlikely. Corrosion protection of all fail-safe parts is necessary; however, an inside part can be better and more easily protected than one that is fully exposed to the Ag corrosives, thus giving an overall safer situation.

In general, many structural concepts exist which can improve those presently used on aircraft through the application of new materials geometric configurations. One example is the lightweight stiffening of columns by the application of composites (boron, graphite, Kevlar) to an existing structure.

7.3.5 Power Plants

Although this study is predicated on power plant technology expected to be available by 1985, it essentially is based on current improved engines in that no significantly new types are expected to be introduced for wide use into Ag service within this time frame. Improvements in power, weight, and fuel consumption (not necessarily simultaneously) of current engines are not expected to be spectacular in nature. For example, fuel consumption improvements are predicted as being in the range of 8 percent for 224-448 k (300 - 600 hp) turbines by 1985. Most of these engines are progressing in their development cycle. Power ratings have been greatly increased, as in one example, from early engine continuous values of 205 k (275 HP) to over 336 k (450 HP) in series production versions (Allison). Concurrent growth in basic dry engine weights has occurred in conjunction with the increased power capacities in most cases. Based on the above, both standard and rubberized current turbine engine data are included in the BHT Ag helicopter synthesis program. Installed weight factors and fuel consumption values for aircraft and converted automotive/aircraft piston engines are noted in Section 7.3.2.

Standby engines, such as blade tip rockets, tip ramjets, gas generators, JATO units, or other pyrotechnique devices, which may add to the vehicle takeoff capability or prolong flight for a limited time in the event of engine failure, are assumed to have an installed weight of about 45.4 kg (100 pounds) for a 1370 kg (3000 pounds) gross weight helicopter. These may be used to increase takeoff payloads to increase productivity, or for safety purposes and, as such, are chargeable to the particular feature. Although these devices fall in the category of 'useful when needed,' they are troublesome and costly. Past testing of these approaches indicated feasibility does exist; system complexity as well as other factors have limited use.

Supercharging for piston engines of helicopters has been used to primarily maintain engine power at altitudes up to 2960m (10,000 feet). It could also be used to improve power outputs up to 30 percent at sea level by using engine pressure boosts of 6 to 9 lb/sq in. This naturally increases engine internal loads and possibly fuel consumption and could be expected to shorten TBO intervals. On-demand supercharging for automotive use has been available for many years and appears in current models as a means of compensating for the inadequate available power of "economical fuel-saving engines." One- or two-minute takeoff power ratings of turbine or piston engines, which may exceed continous ratings by as much as 10 percent, may be valuable for overload or jump takeoffs to increase payload-carrying capabilities of the aircraft.

7.3.6 Stability and Control

Early helicopters hovering without stability augmentation devices tended to be difficult to fly because of the short time period (.5 to 4 seconds typically) associated with attitude divergence. Various devices (gyro bar stabilizers, aerodynamic paddles) to increase the period by providing damping for rotor to fuselage motion have been used for many years to make helicopters more flyable. Gyros in various forms (mechanical, fluidic, and others) have been applied also to produce automatic pilot and other stability aids. In forward flight the rotor tends to be stick-fixed velocity stable but unstable in tip-path-plane attitude. Fuselage stability is achieved by horizontal tail surface control of fuselage pitching moments. The size of these surfaces is often selected to accommodate the rotor angle-of-attack instability.

Controlled stability has thus been a fact of life in helicopter design for many years and may be expected to be an important inherent factor in future aircraft. Its technology is advanced and, in some cases, reflects the latest electronic or other developments (microminiaturization, solid state, fluidics, computers, etc.). Complete control of the helicopter at the normal Ag operating speeds and under wind conditions suitable for spraying liquids appears for all six components, i.e., three directions and three rotations. Unlike an airplane, where coupling of control for direction or rotation forms a basic element in the system, helicopters may change direction without such coupling, i.e., at a constant speed an airplane must rotate in pitch to climb or sink. The need for extra side force control such as might exist for an airplane (wing-tip vertical control surfaces) is thus nonexistent in a normal helicopter.

Adjustable stability and control may be achieved in some controlled stability devices by changes in the feedback loops and the authority of the system. Normally, authorities of Stability Augmentation Systems (SAS) are limited to values which permit safe flight in the event of a hardover failure. Fifteen to twenty-five percent of maximum control motions are typical maximum limits to SAS authority. Changes in control and stability are not expected to be required in utility helicopters converted to Ag uses. In general, their flying characteristics from high gross weights to minimum flying weights are satisfactory from selections of basic utility aircraft parameters. With specials, this may not be the case in that more blade cyclic-pitch motion, higher collective-pitch ranges, and greater hub stiffness or flapping hinge offset for increased control power of the rotor may be needed to ensure sufficient vehicle control in overload takeoff conditions. When the minimum flying weight is achieved, these larger than normal aircraft values may make the vehicle excessively responsive to the pilot input. For this reason, adjustability of automatic stability and control devices for gross weight variations may be required. Having such adjustability, it should be keyed to gross weight changes in such a manner that the pilot is unaware of weight variations from the handling characteristics of the aircraft.

7.3.7 Flight With Ground Effect

One early recognized factor in rotor aerodynamics was the effect of the ground on rotor thrust and power. Figure 48 (Reference 10) shows this relationship as a function of the possible thrust increase at constant power associated with the

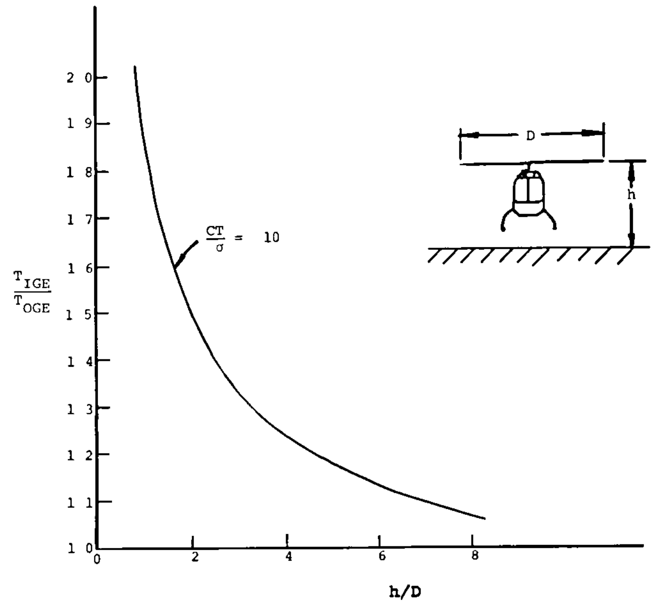


Figure 48. Effect of rotor height on thrust for constant power.

height of the rotor above the ground. Some early production helicopters depended upon this effect for achieving a hovering capability under an overload gross weight condition. Thrust ratio factors from 1.25 to 1.5 for the same power may be generated for a rotor height-to-diameter ratio of .2 for various rotor thrust levels. This effect is minimized in the operation of a practical helicopter (noted in Figure 49), where, at a gross weight of 1354 kg (3000 pounds), the delta lift increase is about 191 kg (420 pounds) or about 14 percent. This, for a .58m (2 foot) skid height above the ground, corresponds to a height-to-diameter ratio of about .33.

One of the most successful Ag helicopter systems in operation at the present time involves the use of the helipad/tank truck type service as illustrated in the frontispiece of this report. One of the drawbacks of this system is the high location of the rotor from the ground at takeoff with consequent minimizing of the ground effect ($h/_D > .60$). Excess available power for takeoff and vehicle acceleration into forward flight is thus reduced compared to ground takeoff (some pilots dislike using the helipad/truck rig with older piston-powered helicopters for this reason).

A modification in truck design which might alleviate this effect and, in fact, which might even permit doubling the aircraft payload appears possible. This would consist of increasing the truck landing area by means of a retractable surface as shown in Figure 50. Rotor $h/_D$ ratios on the order of .15 or less might thus be possible.

This extension surface could be a lightweight tent-like canvas or plastic sheet mounted on an appropriate retractable-for-transport frame. Extension for use and retraction could be based on one or more of the many methods developed for spreading antennae in space. The aircraft would land with the surface retracted; extension before takeoff would be made. Increasing the possible rotor thrust level by a factor of 1.3 for an aircraft with a payload fraction of .30 would double the payload capacity in hovering. Flight from such a pad might be compared to that from the deck of a ship where the ground cushion is lost when the helicopter passes over the rail. The vehicle must be rapidly accelerated to a forward-flight speed where sustaining flight is possible at the overload condition. For safety provisions, it would be desirable to incorporate load dumping in five or less seconds.

Forward flight within ground effect at conventional working speeds (V_W = 40 to 80 mph) for spraying purposes has little effect on the rotor system because of the pathway of the rotor

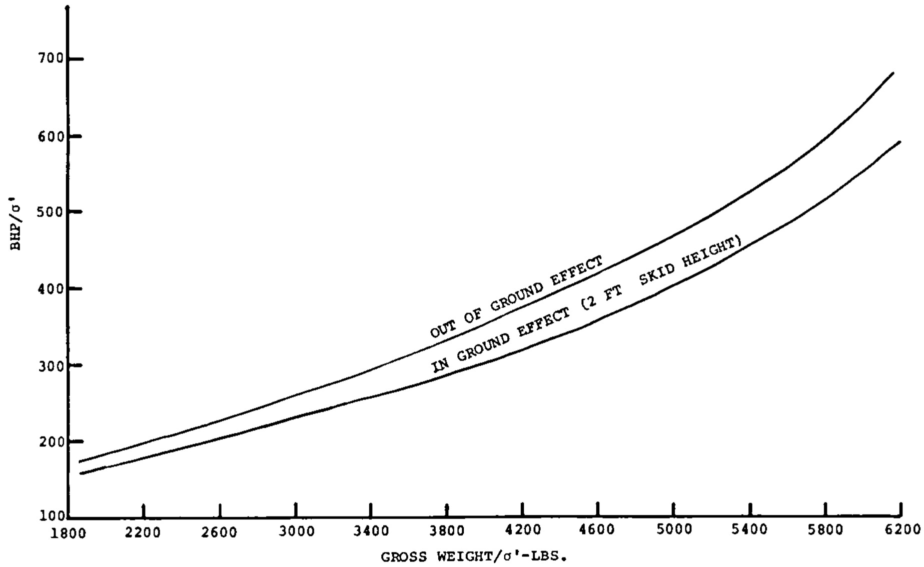
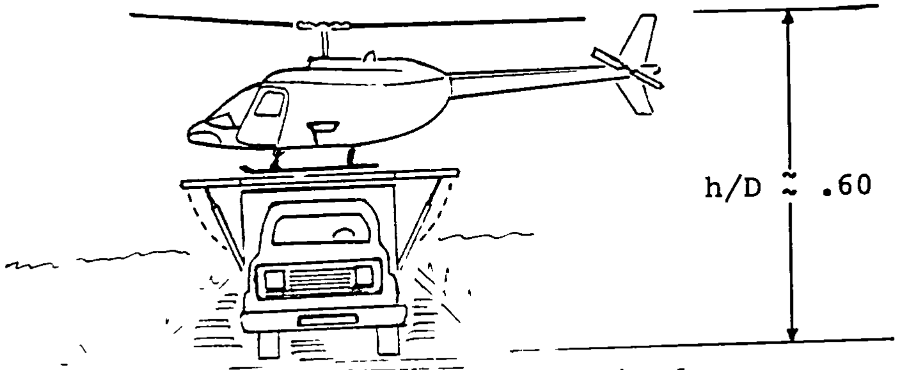
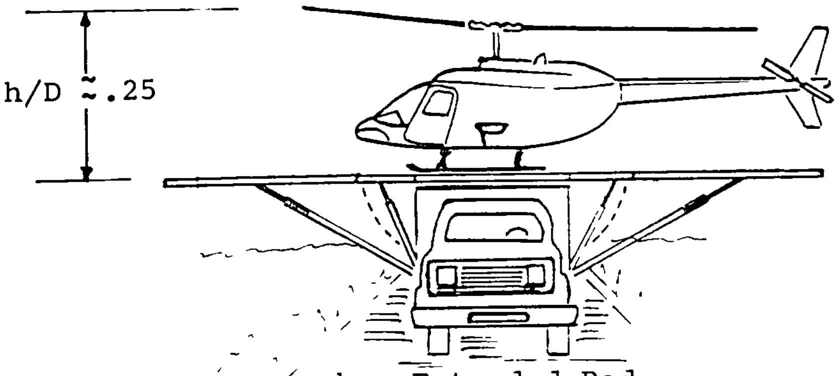


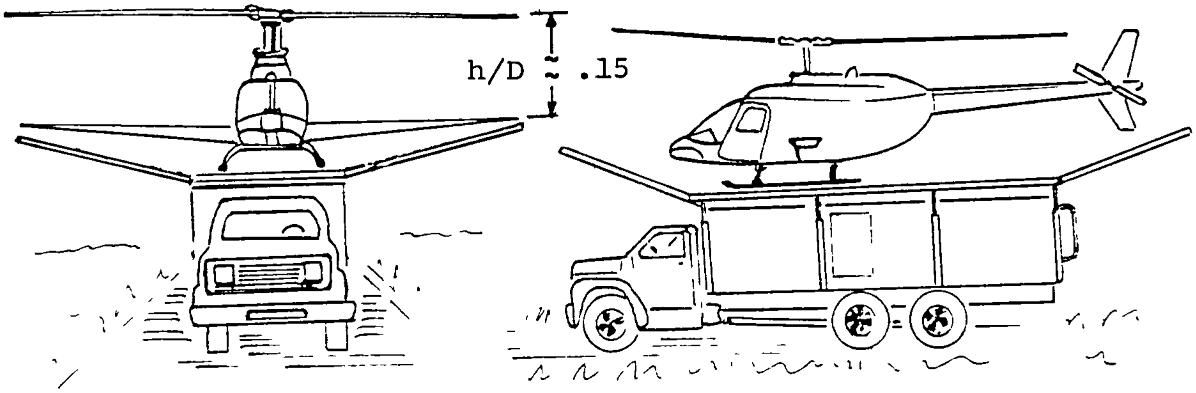
Figure 49. Model 47 helicopter hovering power required 3200 RPM.



a. Normal Practice - Truck/Helipad



b. Extended Pad



c. Extended Pad Raised After Landing

Figure 50. Ground effect augmentation.

slipstream (reference Figure 44). Locating a lifting boom near to the ground is not critical in that the boom chord length is usually quite small and significant augmented wing lift occurs only up to ground heights of less than .5 the chord length.

7.3.8 Specialized Rotors

For many years, efforts to improve rotor systems have been underway by various individuals, aircraft manufacturers, and government agencies because better rotor efficiency with good lift/power characteristics provides the key to effective flight. Some of these concepts may be noted as the following:

- Advancing Blade Concept (ABC - Coaxial)
- Slowed Rotors (High Solidity Rotors - Auxiliary Propulsion)
- Rotor Wing (Wing Lift plus Auxiliary Propulsion)
- Reversed Velocity Rotor (Higher Harmonic Feathering and Auxiliary Propulsion)
- Optimum Pitch Rotor (Cam Feathering Plus Auxiliary Propulsion)
- Jet Flap Rotor (YUAN Rotor)
- Boundary Layer Control (BLC) Sucking and Blowing
- Dorand Jet Rotor
- Circulation Control Rotor (CCR) using the Coanda Effect

These efforts have not had the Ag objectives in mind but were focused on improving helicopter high-speed performance, reducing vibrations, or favorably effecting other parameters such as avoidance of Mach number effect at high altitudes. Model- and full-scale test results of some of these systems are most promising, but for one reason or another, practical application does not often succeed. It appears that complexity of the structure or mechanisms, or meeting power requirements causes failure. For example, relatively accurate wing BLC test information from wind tunnels or flight testing has been available since the early 1920's and such devices have been applied to aircraft. The BLC benefits of obtaining a high $C_{L_{max}}$ are obvious for reducing landing speeds; however, other apparently more cumbersome methods are preferred for transport aircraft (multiple slots, slats, flaps, flaps on flaps, etc.). Based on such experience, the fate of such flow devices appears questionable particularly for Ag use where aircraft and equipment simplicity is a must.

Traditionally, helicopter rotor design parameters are established as compromises among hovering, climb, and high-speed flight requirements. For utility or general aviation helicopters, a high cruise speed with minimum power at low vibration levels is desirable. A criterion for such a rotor selection is based on the fuel parameter of maximum km/kg (mi/lb) plotted against the flight velocity. The peak of this curve usually occurs on a flat portion of the arc; a higher speed is normally selected with an accepted slight penalty in fuel requirements.

For a crane-type helicopter, efficient generation of high lift at lower speeds is more important and rotor parameters would tend to approximate the Ag requirement.

Reference 10 suggests the possibility of saving hovering power through the reduction of the rotor rpm to favorably effect the profile power loss of the rotor. Based on the parameters of the ASP helicopter (reference Section 7.2), power requirements using various rotor blade chords and tip speeds were calculated and the chord variation results are shown in Figure 51.

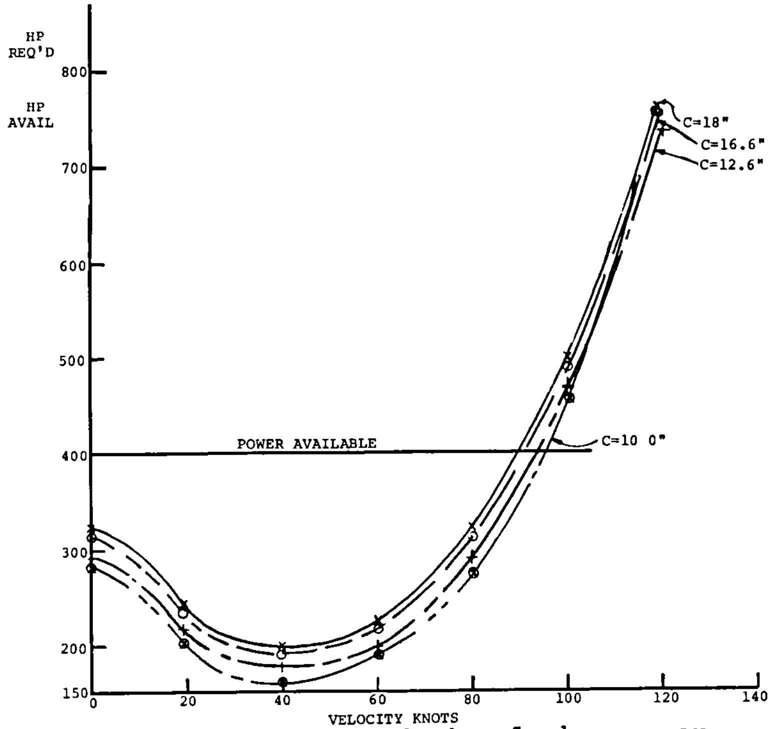


Figure 51. Effect of chord change on power required for aircraft.

Selecting the 10-inch chord rotor tip speed, an RPM variation was evaluated and is plotted in Figure 52. Approximately a 11.15 kw (15 hp) or 10 percent power saving in endurance power (40 kts) and about the same percentage at V_{cruise} (60 to 65 kts) appears available by reducing the tip speed from 178.5 to 153 m/sec (700 to 600 ft/sec). A .204m (12-inch) chord rotor

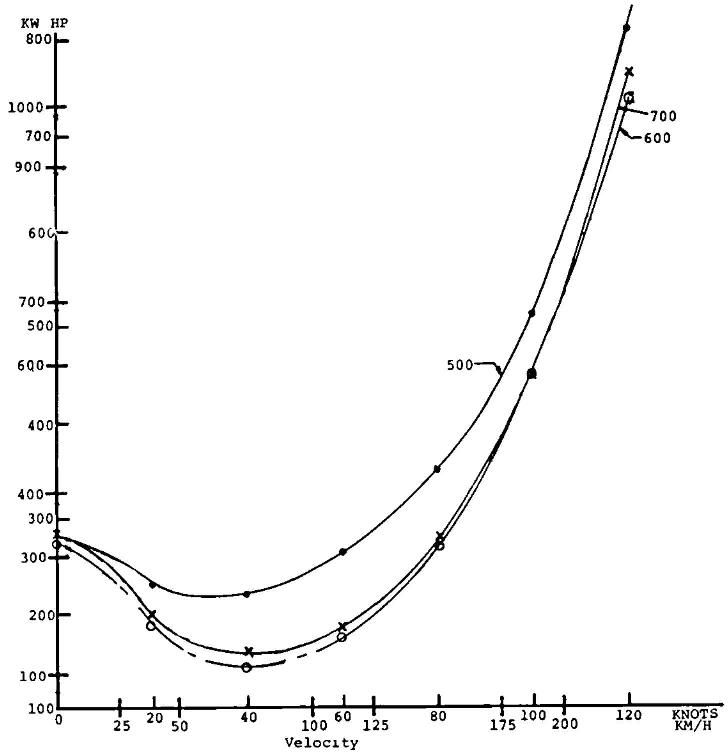


Figure 52. Variations in power required with differing tip speeds.

for the ASP was evaluated for the effect of tip speed variations in hovering and these data are plotted in Figure 53. These curves indicate only a 2.5 percent saving in hovering power by going from 178.5 to 152 m/s (700 ft/sec to a 600 ft/sec) tip speed.

It would appear from the above that a lower than normal tip speed could have beneficial effects when applied to an Ag application where a moderate dispersal speed is required, 96.2 to 128 km/hr (60 to 80 mph). Solid fertilizer spreading speeds tend to be higher, and a high speed power penalty may possibly occur.

Examinations of blade twist, airfoil section, and planform shape effects to save power at low translational speeds should be made to improve rotor aircraft performance. Such an examination is beyond the scope of this study, but these form one of the recommended research items of Section 9.

7.3.9 Servicing and Loading Equipment

The technical quality of the ground servicing and agricultural loading equipment for Ag aircraft is directly related to standard ground materials handling and, in many cases, is the same equipment. Ag aircraft operators and equipment manufacturers have borrowed directly from ground spray rigs for many years for components such as pumps, filters, nozzles, pipes, connections, and many other system parts. Design in such cases is rather haphazard with large factors of safety in some cases and minimum in others. A cast iron pump housing selected for use from ground equipment may weigh three times that of an equivalent aluminum housing but with great savings in cost. Brass nozzles from ground equipment show good service records under corrosive conditions, may be easy to clean, permit rapid replacement of critical parts, and have a wide range of adjustability for handling different crops, sprays, and other variables; however, these are heavy compared to molded plastic or hybrid brass/plastic nozzles.

When new equipment is designed, the latest in materials is often applied in an aircraft fashion to achieve particular results (composites, aluminum, stainless steels, etc.). Two types of dispersal equipment are prevalent - namely, self-powered and driven. The self-powered units involve the use of small air-cooled engines (Briggs and Stratton, Volkswagon, and others) while the driven types basically derive their dispersal power from the engine of the aircraft. Certain advantages accrue to each method; for example, if a helicopter is marginally powered, taking ten or twenty horsepower for dispersal purposes may compromise performance. However, adequate dispersal power may be gained by the use of the secondary power unit while limiting the drain on the helicopter engine to the

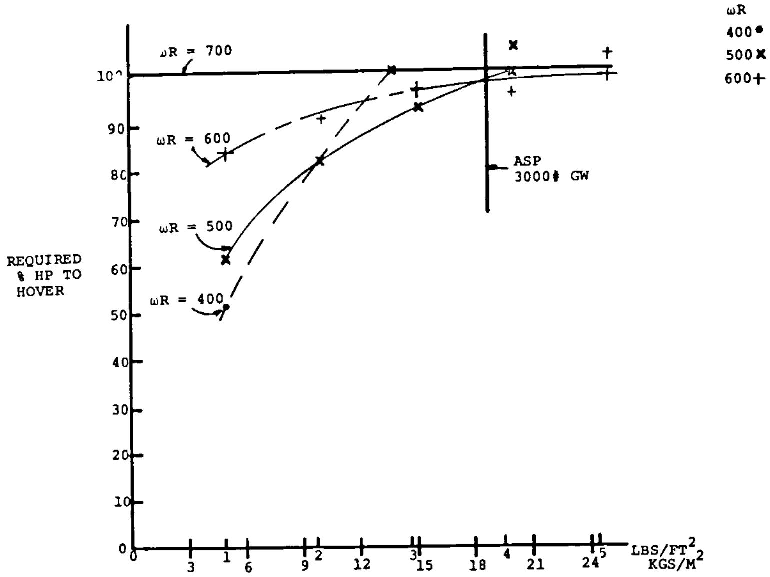


Figure 53. Percent hovering power required.

power necessary to lift the secondary engine weight. When plenty of power is available from the helicopter engine, a power takeoff for dispersal may be a simple mechanical connection to a pump or other devices. Modularizing of self-powered units permits continued operations in the event of service requirements for the pod or engine.

It would be most difficult to improve significantly the technology for adding fuel and liquid dispersal materials to helicopters in that present pumps, filters, water removal equipment (in the case of fuels), as well as associated apparatus permit manual turnaround times from thirty seconds to less than two minutes. This technology is based on normal fixed wing "gas up' equipment which has been developed for many years. Turnaround times of less than 15 seconds exist when two slung units are used as reloading of the empty bucket occurs on the ground during the operating duty cycle. Pickup of a loaded unit occurs in the time it takes to disconnect and reconnect quick fastening lines.

7.3.10 CREATURE CONSIDERATIONS

7.3.10.1 Pilot Effort. In rotary-wing aircraft, the use of hydraulic servo-boosted control systems is the rule rather than the exception, unlike most fixed-wing Ag aircraft that use control surface servo tabs, control balance weights, and various types of bungees to alleviate pilot loads. The lack of emphasis of this factor in the NASA operator surveys (reference Section 1) tends to indicate no problem; however, an improvement in the means of reducing pilot loads through the elimination of dual- or triple-redundancy hydraulic systems would appear desirable. BHT has such a system, designated as the "Inplane Counterweight System" (ICS), flying on a Model 206 bearingless tail rotor. This ICS consists of a centrifugal-weight bungee whose output reacts the centrifugal force restoring moment of the tail rotor blade to provide low mean pedal loads. This may be used on both the main and tail rotor systems; design variations to eliminate cyclic pitching moments appear possible.

Weights of such bungees are compatible with the removed hydraulic systems with possible slight advantages in favor of the bungee; it is expected that improvements in cost, maintainability, and reliability would exist with these bungee sytems.

7.3.10.2 Cockpit Environment. The cockpit environment is controlled by the following interrelated factors:

- Ambient Air Condition

- Temperature
- Pressure
- Humidity
- Contaminants and air quality

  - Dispersed materials
  - Engine products
  - Others

- Noise

- Vibrations

- Cockpit layout

  - Controls

    - Aircraft
    - Systems

  - Instruments

    - Engine
    - Aircraft flight
    - Equipment

The control of temperature, humidity, and the pressure of ambient air in the cockpit by an Environmental Control Unit (ECU) appears to be very desirable from the pilot point of view however, extra cost, service problems, and weight have limited use. Pressurization of the cockpit area to prevent entry of contaminants is also desirable; a concommitant requirement in controlling cockpit air quality is filtering of the entering air to clean out spray poisons, engine combustion products, and other effluvia carried to the cockpit area by rotor downwash. Such filter systems require periodic servicing as does the ECU. Power requirements for ECU systems are between 5 and 15 horsepower depending upon the size of the aircraft and the ambient conditions. A typical piston-powered Ag aircraft (reference Figure 46) has an excess of about 40 horsepower in hovering. A loss of 10 horsepower for ECU use would, therefore, restrict vertical climb performance by about 25 percent which would be quite noticeable to the pilot. The installed weight of such a system approximates 75 pounds which gives a continuous loss of over 6 extra horsepower for carrying the unit in the aircraft.

Noise control to provide a favorable cockpit environment may be achieved by isolating the pilot by means of rubber or other sound-proofing materials from the noise sources. Engine, transmission, and rotor noises are transmitted by the fuselage structure, controls, and air (rotors) to the ear of the pilot.

Stiffening of the cockpit roof transparency panels, the provision of internal damping, or reduced panel transmissibility are practical sound control techniques. Other sound treatments involve reducing the noise at its source by means of rotor design changes (main and tail rotors), sound blanketing, and engine muffling. Rotor noise is related to the following:

- Rotational noise generated by the blade tip vortex usually occuring at a 1/rev frequency

- Noise associated with the generation of lift and dependent upon the blade span loading (C_T/σ parameter)

- Impulse noise generated by impact of the blades on vortices and the impact of the rotor vortices on other structures such as the fuselage, tail surfaces, or possible wings

- Advancing blade tip Mach number effects, as well as Mach stall in the disk

Efforts to control helicopter noise (U.S. Army Quiet Helicopter Program) indicate success in sound control but at a price. To be effective, all sound sources must be treated. Main and tail rotors must be greatly biased in design, i.e., rotor tip speeds must be reduced below 128 m/s (500 ft/sec) with increased blade solidity used to provide sufficient thrust for flight (5 to 7 blades normally required). Complete enclosure of the engine and transmission in sound blankets or a sound box plus cooling means is required. A long and heavy muffler system is additionally required for the engine. The complexity, weight, and cost of this approach precludes its use, particularly for an aircraft mainly used in rural areas. Sound isolation of the pilot for comfort appears to be the practical approach.

Vibration control to prevent fatigue of the pilot is a most important feature to include in the design of the aircraft. Mounting the pilot, instruments, and controls on a damped, moving platform which is spring-isolated from the fuselage permits reducing the transmissibility of the helicopter main rotor forcing functions to the pilot to values less than 10 percent of normal. Hydraulic irreversible control systems prevent blade cyclic loads as well as motion effects from being transmitted to the pilot through the sticks and pedals. A weight estimate for providing pilot isolation is 4 percent of the basic fuselage weight.

Cockpit layout of the controls for the aircraft and system are usually governed by FAA or MIL Specification criteria with adjustability incorporated for individual variations from the norm (95 percentile man). Selection and arrangement of instruments, switches, radios, etc., is an art which usually requires equipment placement and evaluation until pilot satisfaction occurs. Display is a most important factor in the system as discussed in Section 7.3.1.4.

7.3.10.3 Crash Protection. The adequacy of crash protection should normally be visualized as a relative situation based on the expected severity of an accident. Military and civilian aircraft have used design factors for crash protection from 25 to 40 g's vertically and from 10 to 25 g's in a lateral or longitudinal sense. Basic to the control of "g" forces on the pilot are the time and distance over which the deceleration of the vehicle occurs in combination with possible force-limiting energy absorption devices. The force applied to the pilot depends upon his mass and deceleration (controlled by energy absorption devices). Unfortunately, the deceleration distances to limit "g" values for high impact speeds (free fall from 200 feet for example) exceed those normally available to the helicopter designer. Vertical nonfatal crash speeds of 42 ft/sec for military aircraft depend upon landing gear energy absorption plus additional absorption devices. Seats are allowed to progressively fail with honeycomb or other structure being designed to absorb the energy. Such an approach is used in the "Ag special" designs of this study. The increase in weight of such an approach is estimated to cost an additional 3 percent of the basic fuselage weight.

7.3.10.4 Fire Protection. Fire protection may be viewed as consisting of two approaches - namely, as an active and/or a passive system. A passive system is one, for example, which tends to prevent fire by the structural/electrical shielding of wires and fuel lines to prevent severance in crashes, or by the use of rupture-proof or leak-proof fuel tanks. Active systems are those which flood the fuel tank space with an inert gas in the event of a crash or an indicated increase in the temperature/pressure rise of the tank space. Others are inertia-operated electrical systems for fuel valve shutoff of lines or automatic check valve operation for ruptured lines. CO_2 systems for engine fire quenching are considered active systems and may be specified by either manual or automatic control devices. Weights of these items are estimated as 1 percent of the protected item except for the self-sealing fuel tank, where a 10 to 20 percent tank weight delta is assumed.

7.3.10.5 Visibility. The problem of visibility is ranked eighth in importance in Section 1 in the form of the "Accumulation of Dust and Chemicals on the Windshield." Good visibility is related to some of the following requirements:

- Good optical locations of transparencies in relation to the eye of the pilot, i.e., distortion-free images in the main fields of view with shape effects minimized

- Transparency material with high resistance to surface pitting, scarring, or corrosion

- Transparency resistance to transmission of heat

- Simple, reliable, inflight windshield cleaning system(s) using spray and scrub with nonscratch results

- Nonglare internal design for night flying, dawn and dusk operations - shades or moveable darkened transparencies for flying into the sun

- Mirrors for viewing parts normally hidden from the pilot

Location of the boom should be such that spray nozzles may be readily viewed in flight for checking during operation or for possible leakage during shutoff. For night flying, this would require lights on the boom for visual checkout. Viewing of the tips of the boom is most important in clearing trees and other obstacles during turns, and perhaps special vision markers for aiding pilot judgment are in order.

Visual checkout of any field by the pilot prior to spraying usually includes a perimeter flight with one and possibly two diagonals also flown. Wires, under some lighting conditions, are practically invisible which accounts for this flight pattern to permit obstacle viewing from all sides.

Single-engine fixed-wing tractor aircraft tend to suffer visibility problems because of the propeller location. Twin-tractor or single-pusher types permit placing the fixed-wing pilot forward in the vehicle for better visibility but in this respect are not equal to the helicopter. Unfortunately, this good viewing location, in a survey taken many years ago of pilot fatalities of single-pusher versus tractor airplanes, indicated a much higher rate (about 4:1 ratio) for the pilot-forward position.

With the helicopter, additional structure in the form of crash attentuation devices and/or rollover bars are required. This design penalty is discussed in Section 7.3.10.3. Penalties for night vision, i.e., weight of flying light installations and electrical power to see the ground appear to be about 60 pounds plus from 3 to 4 kilowatts of power. Optical devices for marking and locating under poor weather conditions (smog, fog, light rain, etc.) are discussed in Section 7.3.12.

7.3.10.6 Helicopter Safety. Accident rates per 100,000-airplane hours flown for Ag aerial application for the years 1971 through 1974 are shown in Reference 1. These data indicate an average of about a 22.6 accidents with a fatality rate of about 1.8 per 100,000 hours flown. Data on helicopter accidents for the years 1974 through 1976 indicate about 19 accidents with approximately 2.3 fatalities per 100,000 hours. The pilot is charged with causing 65 percent of these accidents either by cutting the control margins too close or by displaying inadequate performance for the situation. Although a lesser number of accidents are chargeable to the aircraft, overall reductions in the rates may be achieved by design improvements of the helicopter, either by making it safer or by alleviating some of the pilot tasks.

Safety design consists of a basic philosophy which pervades the selection of many of the detailed approaches to component design. It also involves features which generally improve the safety of flight operation by their presence, i.e., strike-guarded tail rotors and other components, crashworthy structure, high-energy rotors, automatic engine reignition, bendable booms, multiple engines, fail-safe components, and capacity for a short-time emergency dump of loads. Auxiliary devices such as shoulder harnesses, chip detectors, an engine-out horn, stall warnings, obstacle indicator, automatic fuel shutoff, crash-sealing fuel tanks, onboard fuel monitoring, and other similar devices undoubtedly contribute to safety but are difficult to quantify in terms of beneficial effects on the accident rate. Similarly, cockpit optimization using ambient air quality control, pressurization, air-conditioning, and vibration control benefit the pilot in terms of fatigue effects by maintaining his alertness and normal response rates. If these can extend the safe-flying day by 20 or 30 percent, an improvement number may be attached. In the case of the same number of flight hours with or without these features, the pilot performance at the end of the day might be measurably superior with the cockpit optimization. However, if no accident occurs, differentiation for statistical judgement purposes is difficult.

As a general principle on improving safety by helping the pilot to improve his performance, the aircraft should be more forgiving in nature with features which tend to reduce the load on the pilot. Better vehicle stability and control characteristics, obstacle avoidance operational techniques, improvements in heads-up displays, and prediction of crises by monitoring are in order. Automatic flow control of dispersed materials plus definite shut offs and turn ons could help relieve the pilot effort.

One Ag special concept presented (reference Figure 42) shows a two-man vehicle where the aircraft control effort is achieved by the pilot, but the dispersal effort is carried out by the copilot/operator. The attention of the pilot is on full control of the aircraft while the operator assures full efficiency of the dispersal system, i.e., monitoring of flow rates, material control, swath widths, etc. A compatible split of the duties and periodic reassignment of responsibilities for each station should limit fatigue and increase the safety of operation of the Ag vehicle.

Emergency reserve power installations permit a fallback position for continuing limited flight in the event of prime mover power failure. The safety and control of rocket systems or other approaches in crashes is questionable and tends to limit use.

7.3.11 Subsystem/Interface Problems

Subsystem/interface problems may be expected to occur and some of these are noted with possible solutions or methods of avoidance in Table 9.

7.3.12 Operational Considerations

7.3.12.1 Direct Lift. Direct lift may be achieved by the addition of a small wing or by making the main spray boom member into a lifting surface. It would appear that some advantage could be gained if the boom member could be converted into a lifting surface as per the following:

- The boom is needed in any event for spraying; therefore, weight penalties would be expected to be minimized over the use of a wing.

- The average helicopter wing may have a hovering power interference loss as high as 15 percent. A high aspect ratio boom/wing might be expected to have a lesser interference as the needed projected area would tend to be less than that of a wing.

- A round tube (best for carrying internal pressure) has about 10 times the drag of an equivalent frontal area streamlined section.

In general, any reduction in power required should be beneficial to fuel consumption provided the power plant characteristics are properly matched to the aircraft.

TABLE 9. SUBSYSTEM INTERFACE PROBLEMS

Subsystem	Problem	Solutions	Remarks
A. Spray System			
1. Boom-vehicle attached	1. Transportation	1. Foldable or detachable design locked to fuselage for transport	Leakproof and quick disconnect essential
	2. Ground or obstacle strike	2. Bendable or breakaway design feature	Same as 1
	3. Hardpoint locations needed on aircraft	3. Specified by mfg in design phase	Rapid removal requirement
	4. Spray nozzle location control for even distribution	4. Moveable, controlled flow nozzles - selected by pilot/copilot	Ground adjustable. Variable air control
2. Boom-slung	1. Transportation to site	1. Ground vehicle	
	2. Alignment to flight path	2. High directional stability of slung load req'd	

TABLE 9. (CONTINUED)

Subsystem	Problem	Solutions	Remarks
	3. Effects of weight changes on vehicle/ load stability	3. Automatic stability device	
	4. Velocity limitation to spraying	4. Improve slung load/aircraft dynamics	
	5. High drag	5. Streamline pod and boom	
	6. Ground strike	6. Severance cutter system	Pyrotechnic or other cutter
3. Tanks	1. Leakage	1. Self-sealing	
	2. Slosh	2. Baffles	
	3. Attachment	3. Designed to hardpoints	
4. Pumps, valves, controls	1. Leakage	1. Bypass suction on seals or canning	

TABLE 9. (CONCLUDED)

Subsystem	Problem	Solutions	Remarks
	2. Pressure control	2. Pressure regulators to control surge	
	3. Wear	3. Balanced pressure designs	
	4. Power reduction	4. Use high efficiency type	
B. Marking Devices	Mounting means	Miniaturization	
C. Displays	Pilot distraction from flying aircraft	Heads-up display	

- Lift sharing between a rotor and a wing may be a major problem in that a variable angle-of-attack control for the wing becomes a necessity with translational velocity and gross weight changes; i.e., wing/body trim must be made for both steady and rapid flight attitude changes.

- The amount of lift generated by a wing surface subtracts from the required rotor thrust and indirectly from its propulsive capacity. For this reason, helicopter wing lifts are usually limited to less than 25 percent of the aircraft gross weight unless auxiliary propulsion is used.

The use of direct lift on an Ag helicopter implies its proper control during maneuvers; i.e., turns, banking, etc. The limitation of wing technology are thus added to those of rotor technology in the design of an Ag vehicle. Perhaps the most difficult maneuver for the pilot is the repetition of turns (12 seconds average time for helicopter, 30 seconds for aircraft). Unless an automatic wing incidence control is included in the design, this function is thus added for the pilot, increasing his burden. An automatic lift splitter device (wing and rotor split) could be expected to be relatively complex, thus tending to be counterproductive to the simple approach necessary for the Ag aircraft. Research to determine the best use of a lifting versus a nonlifting but steamlined boom needs to be conducted.

If a lifting boom is used, the following rationale may be assumed - namely, a 5 percent of gross weight lift from the boom at an L/D ratio of 20, and rotor L/D values of about 7.

The rotor lift reduction will be 150 pounds for a gross weight of 3000 pounds and the boom lift will be the same. Rotor horsepower savings in forward flight will be about 15.1 lb/hp for normal rotor parameters; therefore, 10 rotor horsepower will be saved. At an L/D of 20, the boom drag for 150 pounds lift would be 7.5 pounds at 60 mph.

$$\text{Boom hp} = \frac{DV}{375} = \frac{(7.5)(60)}{375} = 1.2 \text{ hp}$$

$$HP_{\text{Saved}} = 10 - 1.2$$

$$= 8.8 \text{ hp}$$

at 15 lb/hp the equivalent weight would be:

$$W_C = (8.8)(15)$$

$$= 133 \text{ lb}$$

For a W_f of 50 percent and a 3000 lb gw, this represents:

$$\% \text{ Saving} = \frac{133}{(.50)(3000)} = 8.9\% \text{ of Weight Empty Fraction}$$

7.3.12.2 <u>Drag</u>

A typical 15.3m (60-foot) span spray boom, as shown in Figure 7-6, may be assumed to have the following drag characteristics:

Component size

Main Tube = 2 in. dia x 60 ft

Support Tube = 1 in. dia. x 160 ft

Spacer Tube = .75 in. dia x 100 ft

Based on a frontal area drag coefficient of 1.15 (Reference 1):

$$D_A = (\frac{2}{12})(60) + (\frac{1}{12})(160) + (\frac{.75}{12})(100)$$

$$= 10 + 13.33 + 6.25$$

$$= 29.58 \text{ sq ft}$$

At 100 mph:

$$D = \frac{1}{2} C_D \rho SV^2$$

$$D = (1.15)(\frac{.002378}{2})(29.58)(146.7)^2 = 955 \text{ lb}$$

A 60-foot span streamlined boom (nonlifting) could be expected to have the following drag:

Assuming a 2 inch diameter tube streamlined to have a t/c ratio of .18, the drag coefficient based on the frontal area is about .10 (Reference 11).

$$\text{Drag} = (955)(\frac{.10}{1.15}) = 83 \text{ lb}$$

This represents a drag decrease of:

$$D = 955\text{-}83 - 872 \text{ lb}$$

$$\Delta HP = \frac{DV}{375} = \frac{(872)(100)}{375} = 230 \text{ hp saved}$$

The above computation neglects interference drag as well as other possible corrections but is presented as an indication of one of the major, but most easily treatable, horsepower loss items in Ag helicopter systems.

As a recommended area for research, drag reduction is expected to be most productive in limiting horsepower losses.

7.3.12.3 Side Force Control. The purpose of side force control is to either turn the aircraft in a tighter circle in a directional sense, or to cause rapid lateral displacements of the vehicle. It may be envisioned that such a control would permit avoidance of obstacles by lateral motion of the vehicle. It could be expected that this type of control would give the vehicle more agility and permit more rapid turns (less turn radius required).

Reference 5 indicates that changing the turn time from 12 to 7 seconds is a saving of about 7 to 8 percent of the mission flight time. The penalty paid for this is flight at a 1.6g level. Pilot fatigue is expected to limit this type of operation severely. As most spraying flight occurs at low speeds (100 mph or less), it would appear that the need for a rapid acting lateral motion control for the helicopter vehicle is not really necessary. As a desirable 6-axis control already exists for a normal helicopter, this addition would appear superfluous.

7.3.12.4 Avionics Display - Agricultural Task. The pilot performing aerial dispersal in both fixed wing aircraft and helicopters has a very high work load. The requirement to fly a low-altitude precision track with frequent 180-degree turns forces a concentration on the external scene. It is difficult under these circumstances for the pilot to observe internal cockpit information such as warning lights, and instruments or track information if a guidance system is used. A heads-up display (HUD), which would present the information superimposed on the exterior scene, would reduce work load and should improve performance and safety.

The characteristics of aircraft used in Ag dispersals make lightweight displays important. Also, the requirement to look over wide angles during turns, makes a head-mounted display (HMD) more attractive than a fixed-mount type HUD.

BHT has developed a subminiature HMD which contains an optical system mounted on an eyeglass and displays a virtual image from a projector on the field of view of the wearer (Figure 54). The prime objective is to provide a pilot with a light-weight inexpensive head-mounted display. An operational version of the display would consist of a micromirror and small display element fitted to the personal eyeglass frames of each pilot. Being personally fitted, no adjusting mechanism would be necessary. The projector can be an array of miniature light-emitting diodes with the desired information presented. Liquid crystal or other techniques that can generate a miniature display image can also be used. The optics of the display are extremely simple. The miniature reflecting mirror is a simple spherical mirror. This design has sufficient resolution to show numeric and most aircraft instrument information. If a television image were to be shown (assuming it could be generated on the small image surface), the use of an aspheric-type mirror is quite practical.

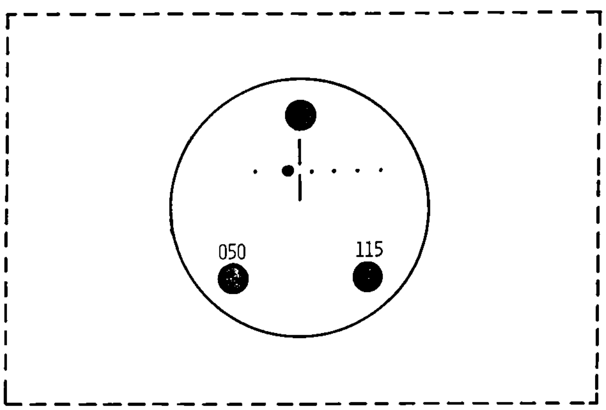


Figure 54. Symbology.

An experimental model of the display has been provided to the Army Aeromedical Research Group at Fort Rucker, Alabama (see Figures 55 and 56). This display has two numerics which are presented either as absolute altitude or airspeed during flight. Figure 57 shows the experimental display being worn by an Army pilot.

The information most required in "heads-up" form for the agriculture mission includes absolute altitude with low-altitude warning, airspeed with low-airspeed warning, track alignment indication, and master caution warning. Figure 58 shows an example of how such information could be displayed on the subminiature HMD.

Considerable advantage might be gained by operating at night. The heads-up display of information is especially important during reduced visibility. The brightness of the information displayed can be adjusted so best advantage can be taken of an existing illumination for direct vision. The displayed image, showing flight and aircraft condition parameters, as well as track and warning information, would be observed as superimposed on the external background. A contract has been negotiated by BHT with the U.S. Army at Ft. Rucker, Alabama to use the same subminiature optics technique to superimpose numerical information on the nightvision goggles (NVG). This would allow a pilot to see airspeed, altitude, etc., superimposed within the image seen on the NVG system (Figure 58). Such a system might be used for night spraying for the Ag mission.

The subminiature HMD has the potential of being developed to present sophisticated information. The use of a miniature X-Y matrix with a microprocessor-controlled display generator would give the opportunity of presenting complex dynamic symbology or pictorial type information. It would be possible to present ground stabilized information, i.e., a track line that would appear aligned along the actual desired flight path, if a head-tracking mechanism were used with the subminiature HMD. Such trackers are common on armed helicopters. The aircraft attitude terms would also have to be considered to display the information in ground-stabilized form. If such a system were designed, the spray pilot could line up successive passes across a field simply by flying to the ground-stabilized track line.

The subminiature display is in an early state of development but can be considered a practical item for development to aid the agricultural pilot.

7.3.12.5 Lofted Swath Effects. Appendix C presents a general discussion of the generation of helicopter swaths and their widths. It is apparent that many diverse effects may occur depending upon the methods and means of injection of the spray

Figure 55. Experimental model display.

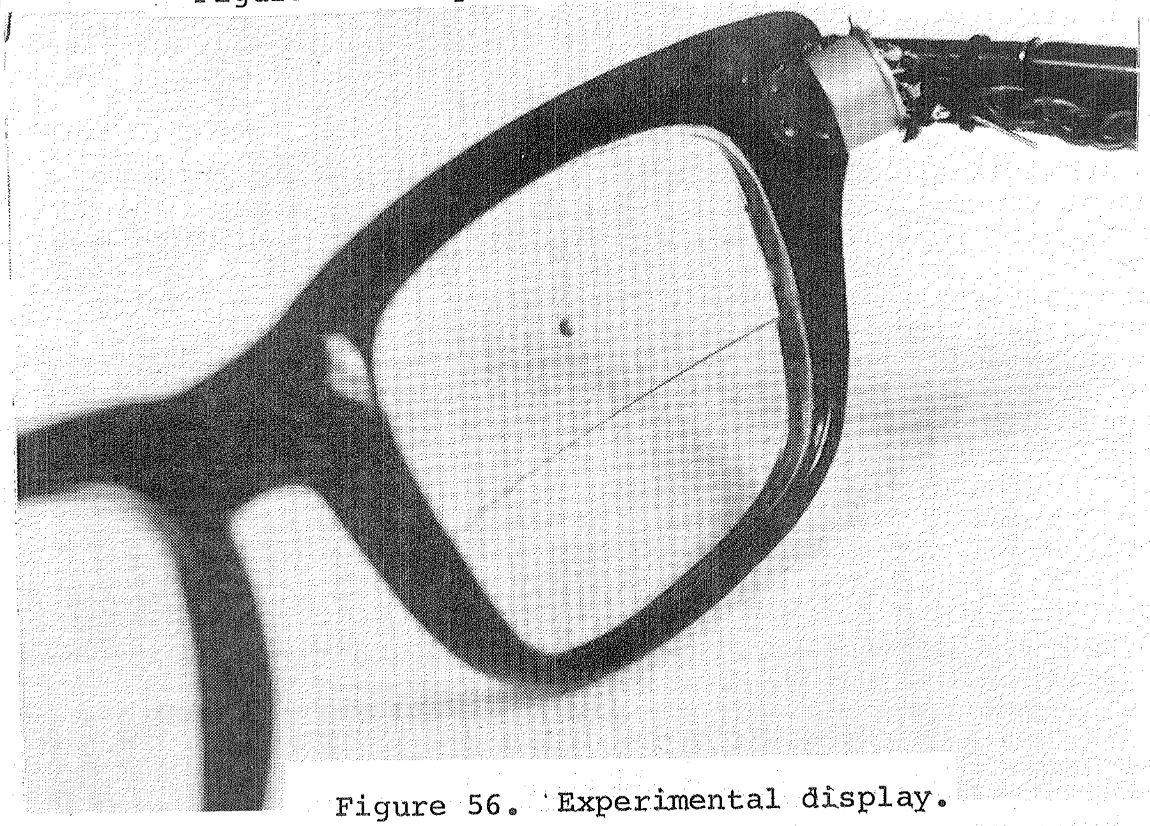


Figure 56. Experimental display.

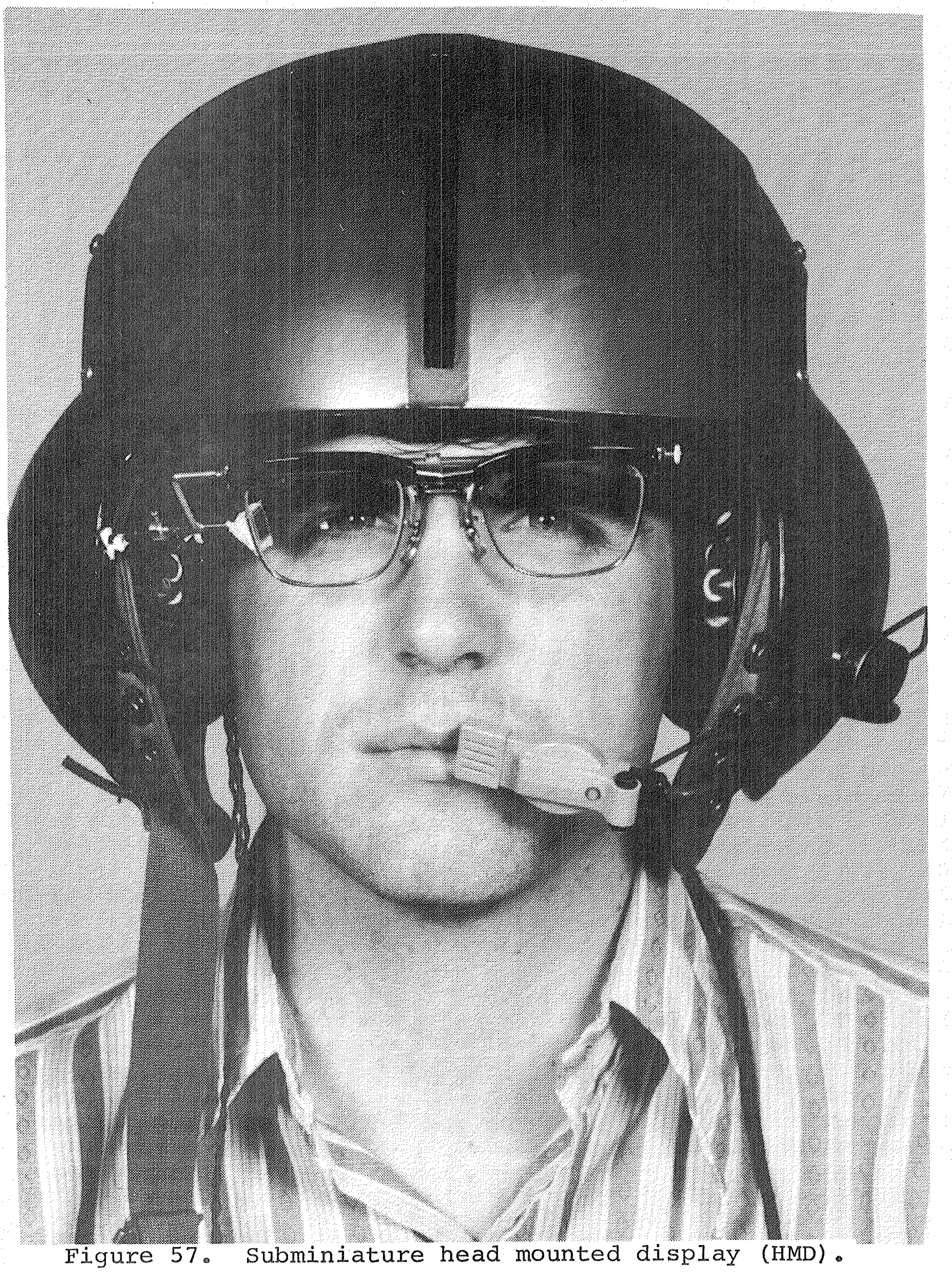


Figure 57. Subminiature head mounted display (HMD).

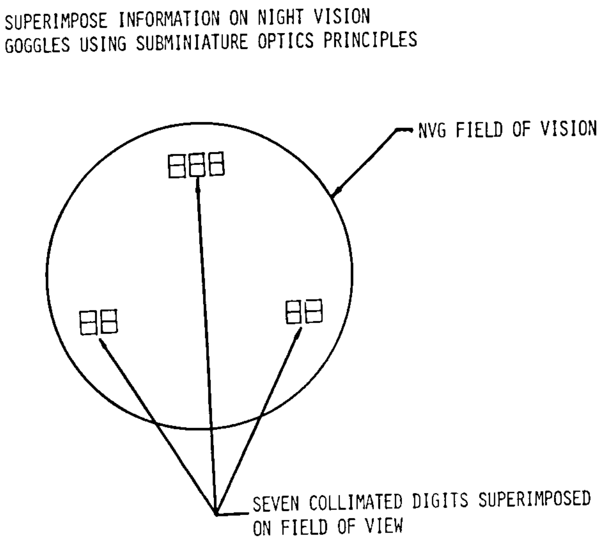


Figure 58. Night vision goggle program.

into the airstream. Figure 59 shows the spray material ground distribution of a lofted swath. It appears from Figures C-4 and C-5 that boom spray injection near or beyond the tips of the blade would permit the tip vortices to loft the spray to create a wide swath. Recent tests run in Yakima, Washington at the U.S. Department of Agriculture spray range on a BHT Model 206 with a Simplex Manufacturing Company spray rig indicate this is indeed the case. Using a basic 35-foot span boom which extends several feet beyond the blade tips, spray material was injected into a lofting cycle to give swath widths exceeding 80 feet or about 2.5 times the boom width. A normal 35 foot span boom under no-wind nonlofted conditions can be expected to give about a 50-foot maximum width swath. Control of the fines appeared within reason. A special flying technique was used to accomplish this swath in that turn on and turn off was made under steady state flight conditions, i.e., approaches to the swath were made without plunging and turn off occurred before climb-out at the end of the row.

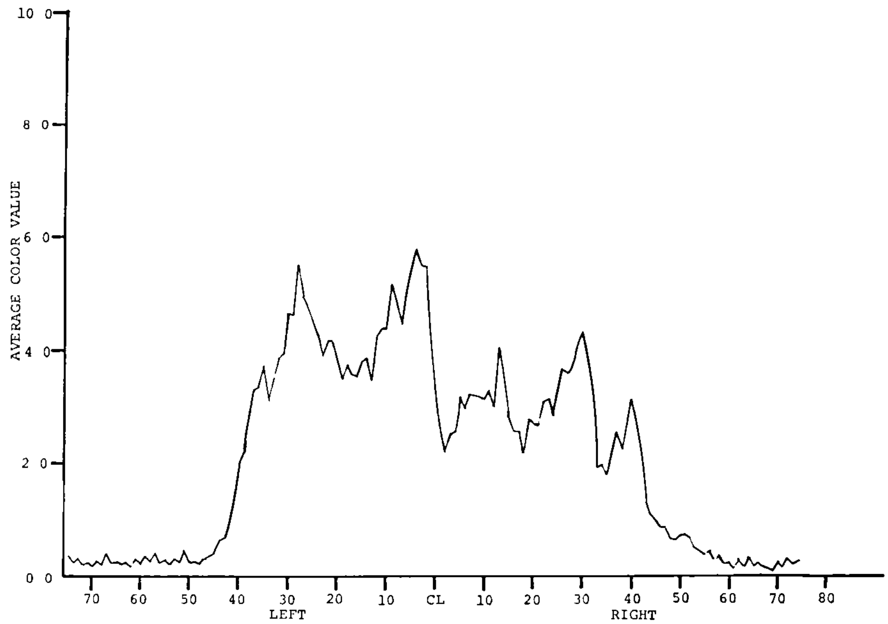


Figure 59. Lofted swath - 35-foot boom length, 33-foot diameter rotor.

Additionally, a 22-foot span boom was tested to evaluate the effects of eliminating the tip vortex. A negligible increase in swath width occurred in this case. It would appear that if the size of the droplet could be rigidly controlled to eliminate the fines and lofted injection is used, that significant increases in swath width could be made available. These tests were run up and down wind at wind velocities less than 4 mph. If crosswind effects were added to the above, it would appear that larger increases in PIP would occur. Computer runs including 200-foot width swaths were made to investigate this effect.

7.3.13 Environmental Consideration

Environmental considerations at present have a moderate impact on Ag aircraft devices; however, in the future they may have a large influence on the Ag national aerial distribution systems from two points of view - one, the need to protect both the environment and people from maldistributed poisons or other possibly harmful substances, and second, the requirement that the natural life cycle of nonrelevant growth be undisturbed.

State, federal, and local regulations generally cover most of the known poison problems; disturbance of the natural life cycle of many species and growth is being monitored by many groups with encouraging results. Pollution protection of the environment (smog, noise) from ground-support equipment and/or pod aircraft engines has the same considerations and may be controlled as on automotive transportation. These functions are under the control of the engine manufacturer. Contemporary and future clean burning engines for the above noted equipment will undoubtedly be produced with weight/horsepower penalties tied to the engineering quality of the manufacturer as has been demonstrated by the automobile companies. An engine may be designed to burn fuel cleanly and be nonpolluting without weight/horsepower penalties, or dirty combustion may be used with the need of ancilliary apparatus to meet clean air requirements. The second method is heavy and more failure prone from the complexity and number of extra apparatus parts.

No engine weight/power penalties have been included in this study as it is assumed that engines for the 1985 timeframe will have solved the pollution problem by the application of clean burning techniques. Noise impacts on the natural species and growth environment are unknown although many opinions exist. Claims of the ill effects of aircraft noise on setting hens, pregnant pigs, and other animals have been prevalent for years. Proof of such ill effects from noise is difficult to establish. In view of the rural helicopter operating environment, no Ag sound control systems were established.

7.3.14 Tradeoffs

Vehicles to be analyzed are shown in Table 10 and have the following characteristics:

- Gross Weight Range
    - 3000 lb
    - 6000 lb
    - 12000 lb
- Technology level
    - Standard Utility
        - Present Day
        - 1985 Improved — Turbines
        - New Designs
    - Specials
        - Present Dynamic Components

TABLE 10. FEATURES SELECTED - FACTORS TO MODIFY SYNTHESIS PROGRAM

	I	II	III	IV	V
	MODEL ITEM	DESIGN FEATURES TECHNOLOGY LEVEL	EFFECTS ON W.E. FRACTION INCREASE %	DECREASE %	TOTAL CHANGE % III % IV
1.	Standard	Per current program	-	-	-
2.	Standard	1. Composite use in structures		10	+.1
		2. Crashworthiness	3		
		3. High energy rotor	2.5		
		4. Creature comfort			
		Press. & air cond.	3.3		
		Vibration isolation	4.0		
		Fire protection	.3		
		Visibility	.4		
		Pesticide avoidance	.3		
		5. Environmental			
		Engine noise	.3		
		Engine fuel control	.2		
		Main rotor	2.5		
		Exhaust treatment	1.0		
		6. Boom improvement (Fwd flight)		-7.9	

TABLE 10. (CONTINUED)

I MODEL ITEM	II DESIGN FEATURES TECHNOLOGY LEVEL	III EFFECTS ON W.E. FRACTION INCREASE %	IV DECREASE %	V TOTAL CHANGE % III % IV
3. Standard favorable 1985 mods only	1. Composite structure	-	10	-17.9
	2. Boom improvement (fwd flight eq. wt.)	-	7.9	
4. Specials present dynamic components	1. Composite structure		20	-10.1
	2. Crashworthiness	3		
	3. High energy rotor	2.5		
	4. Creature comfort	8.3		
	5. Environmental	4.0		
	6. Boom improvement		7.9	
5. Specials favorable mods only	1. Composite structure		20	-34.9
	2. Boom improvement		7.9	
6. Specials - new	1. Composite structure		20	-37.9
	2. Boom improvement		7.9	
	3. New dynamic combinations		10	

TABLE 10. (CONCLUDED)

I	II	III	IV	V
MODEL ITEM	DESIGN FEATURES TECHNOLOGY LEVEL	EFFECTS ON W.E. INCREASE %	FRACTION DECREASE %	TOTAL CHANGE % III % IV
7. Specials	1. No 6 favorable		37.9	-20.1
with all	2. No 2 increases	17.8		

- Contemporary Materials
- Contemporary Engines

  - Piston

    Automotive
    Aircraft

  - Turbines

- Contemporary Technology

- New Dynamic Components

  - New Materials
  - Developed Engines
  - Advanced Technology

- Mission Profiles - As defined in Sections 5 and 8.1

7.3.15 <u>High Lift Systems</u>

High lift rotor systems have been reviewed in Section 7.3.7 of this study resulting in the general conclusion that these have little to offer in a practical sense for Ag helicopter dispersal systems. Direct lift wings have limited use for Ag systems helicopters, and wing $C_{L_{max}}$ improvements, although available, have limited appeal. Fixed wing aircraft need as high a $C_{L_{max}}$ as possible with the associated propulsive power available to maintain flight speeds above a stall to minimize the aircraft turn radius. This permits a minimum turning time for the airplane. Helicopter turning times (10-12 seconds turn versus 30-45 seconds for the airplane) do not reflect this need (reference Section 2.3) on standard factor turning times.

7.3.16 <u>Flight Path Control Without Pitch Attitude Change</u>

A device may be incorporated into the helicopter which would permit altitude changes of the vehicle without changing the pitch angle of the fuselage and boom. This could be accomplished by using pilot-induced main rotor collective pitch changes with automatic trim devices for main rotor cyclic and tail rotor pitch angles. This would permit forward flight fuselage trim at the position of its most efficient angle (least drag versus attitude angle) with a consequent saving in power required. Additional advantages might be the constant nontilting position of the pilot providing better visibility and causing less fatigue. Sensing and control of the fuselage trim positions for various aircraft gross weights would be a portion of the duties of such devices. Analysis of such a device indicates the following:

- For spraying at 60 mph, the delta horsepower savings by best fuselage trim angle versus a normal type trim angle is about 20 percent in drag (determined by body wind tunnel tests). For a 10-square-foot frontal area fuselage at 60 mph, this would be the following:

$$D = \frac{1}{2} C_D SV^2$$

$$D = (1.0)\left(\frac{.002378}{2}\right)(10)\ (88)^2 = 92 \text{ lb}$$

$$\text{Delta Drag} = (9.2)(.20) = 18.4 \text{ lb}$$

$$hp = \frac{DV}{375} = \frac{(18.4)\ 60)}{375} = 2.95 \text{ hp}$$

This appears to be a neglible saving compared to the cost and weight of such a device.

- Quantifying the effects of pilot position and better visibility is a most difficult task and beyond the scope of this study; however, a favorable consideration of devices that increase the complexity of a helicopter control system should indicate great and significant improvements prior to use. This does not appear to be the case in this situation.

8. ANALYSIS

8.1 TYPICAL MISSION PROFILES

Evolution of the three typical mission profiles was based on discussions with helicopter operators, pilots, and involved personnel in the Ag aerial dispersal business. A random selection of fields, aspect ratios, temperatures, locations, altitudes, and other pertinent data was made to approximate real-life situations. Other practical factors influencing typical missions were as follows (reference Section 7.1.3):

- A two-man operation is the minimum number essential for efficiency - namely, the pilot and a ground crew person who drives a service truck, mixes the liquids, and loads the helicopter. Close coordination via a radio link is maintained at all times. The ground person is a vital part of the operation in that 45-second to 2-minute turn-around times are essential to generate profitable activities.

- The ground crewman also may use the truck as a marker for swath positioning.

- Apparatus to provide for the creature comfort of the pilot is considered secondary (air conditioning, cockpit pressurization). The extra cost for these items, plus the adverse weight effects on payload, tends to limit use.

- As a general principle, special nonessential equipment costs and possible effects of any apparatus or technique that degradates aircraft performance are to be avoided. Conversely, methodologies to increase payload capabilities or aircraft effectiveness are worthy of consideration.

- Review of the FAA regulations as applied to Ag helicopters indicated similar conclusions, i.e., regulation changes that improve the payload weight fraction without overly compromising the gross weight (stability, control, load factor) are in order.

<u>Operator A - Typical Mission</u> (reference Figure 60)

Altitude S.L.

Temperature 80°F

Ferry speed @ altitude - 500 ft, 80 mph, T = 60°F

Hover Requirements

IGE	S.L.	80°F
OGE	S.L.	80°F

Hot Day Performance:

Temperature 100°F

Altitude S.L.

Turning Time 12 sec/turn

Loading Time (min) .75 to 2.0
.75 slung load
2.00 belly tanks

Fertilizing Speed 80 mph
Spray Speed 60 mph

Application Rate

16 lb/acre
32 lb/acre
100 lb/acre

<u>Operator B - Typical Mission</u> (reference Figure 61)

Altitude Fields 1-7 S.L. 8000 ft

Temperature S.L. 90°F Altitude 80°F

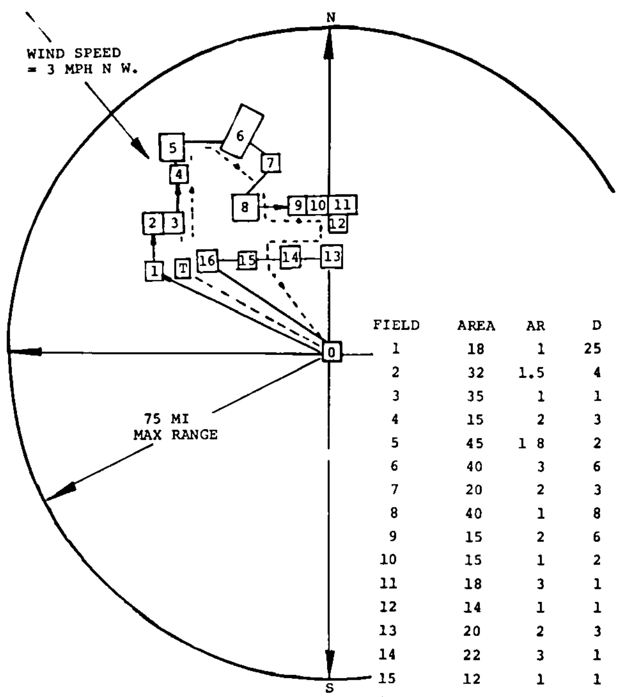
Ferry speed @ altitude - 85 mph @ 500 ft

Ferry speed @ altitude - 90 mph @ 3500 ft

Hover Requirement

IGE	S.L.	3000 ft
OGE	90°F	3000 ft

TREATS 16 FIELDS/DAY - AVERAGE AREA PER FIELD EQUALS 25 ACRES - MAXIMUM ACRES EQUALS 40 - MINIMUM SIZE TREATMENT OVER SEVEN MILES AWAY IS 20 ACRES.

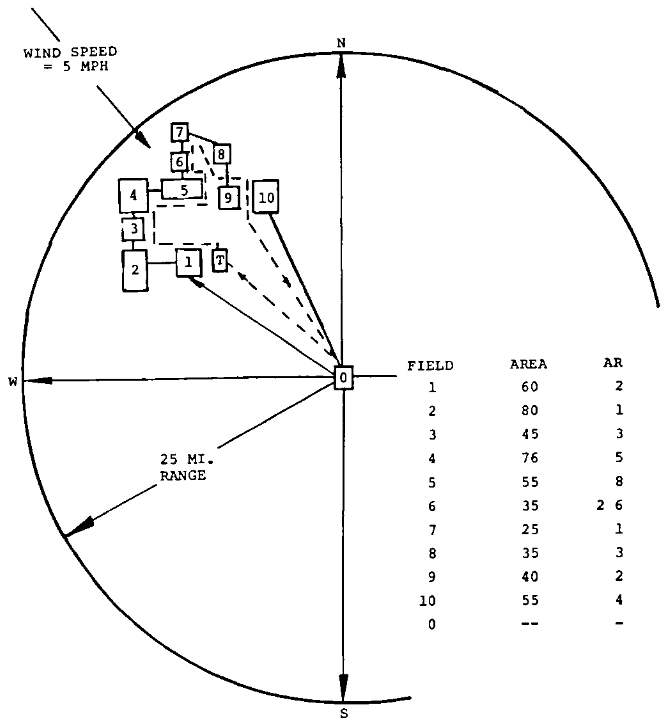


FIELD	AREA	AR	D
1	18	1	25
2	32	1.5	4
3	35	1	1
4	15	2	3
5	45	1 8	2
6	40	3	6
7	20	2	3
8	40	1	8
9	15	2	6
10	15	1	2
11	18	3	1
12	14	1	1
13	20	2	3
14	22	3	1
15	12	1	1
16	23	2	1
0	--	-	20

D = DISTANCE FROM HOME, LAST FIELD, OR INTERFIELD DISTANCE, MI.

Figure 60. Operator A - typical mission.

TREATS 10 FIELDS PER DAY - AVERAGE SIZE EQUALS 45 ACRES -
MINIMUM SIZE EQUALS 10 ACRES - MAXIMUM SIZE EQUALS 80 ACRES -



FIELD	AREA	AR	D
1	60	2	10
2	80	1	3
3	45	3	1
4	76	5	2
5	55	8	6
6	35	2 6	1
7	25	1	2
8	35	3	4
9	40	2	6
10	55	4	3
0	--	-	16

D = DISTANCE FROM HOME, LAST FIELD, OR INTERFIELD DISTANCE, MI.

Figure 61. Operator B - typical mission.

Hot Day Performance:

Temperature	100°F
Altitude	3500 ft

Turning Time	12 sec/turn
Loading Time (min)	.75 to 2.0 .75 slung load 2.00 belly tanks
Fertilizer Speed	80 mph
Spray Speed	60 mph

Application Rate

16 lb/acre
32 lb/acre
100 lb/acre

Operator C - Typical Mission (reference Figure 62)

Altitude	S.L.
Temperature	90°F

Ferry speed @ altitude = 80 mph

Hover Requirement

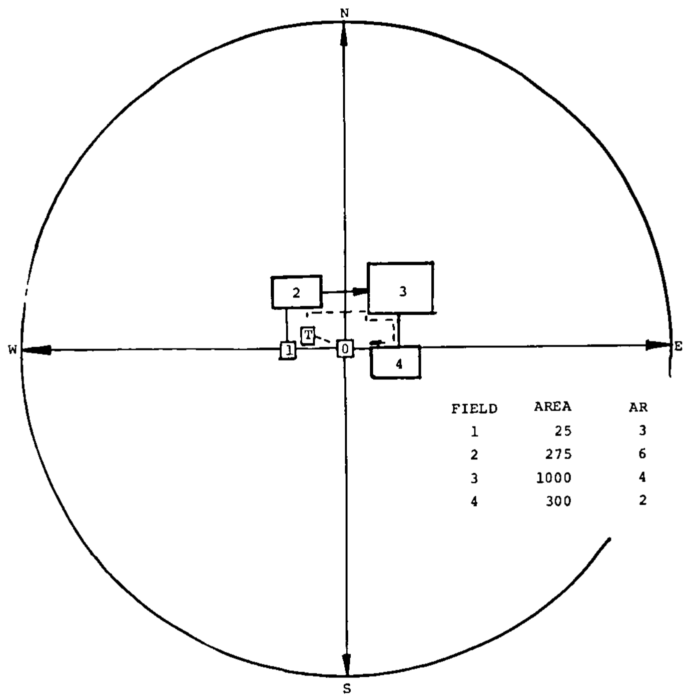
IGE	S.L. 3000 ft
OGE	S.L. 3000 ft

Hot Day

Temperature	100°F
Altitude	3500 ft

Turning Time	12 sec/turn
Loading Time	.75 to 2.0 .75 slung load 2.00 belly tank
Fertilizer Speed	100 mph
Spray Speed	80 mph

TEN TO TWELVE MONTH GROWING SEASON - MOBILE BASE - TRUCK SYSTEM - AVERAGE SIZE FIELD EQUALS 200 ACRES - MAXIMUM EQUALS 1000 ACRES - MINIMUM EQUALS 25 ACRES.



FIELD	AREA	AR	D
1	25	3	0
2	275	6	1
3	1000	4	1
4	300	2	2

D = DISTANCE FROM HOME, LAST FIELD, OR INTERFIELD DISTANCE, MI.

* ASSUME FERRY SPEED FROM LAST JOB IS EQUAL TO 80 MPH FOR A DISTANCE OF 25 MI

Figure 62. Operator C - typical mission.

Application Rate

16 lb/acre
32 lb/acre
100 lb/acre

8.2 AERIAL VERSUS GROUND APPLICATION

Comparison costs to treat twenty-five acre fields of varying aspect ratios are presented in Figure 63 for a helicopter ($122/hr), an airplane ($60/hr), and a ground rig ($15/hr). These data are based only on the operating time to actually treat the field with the assumption that the dispersed load is sufficient for the treatment and is equal for all vehicles. In addition, no ferrying, loading, or turnaround times are included.

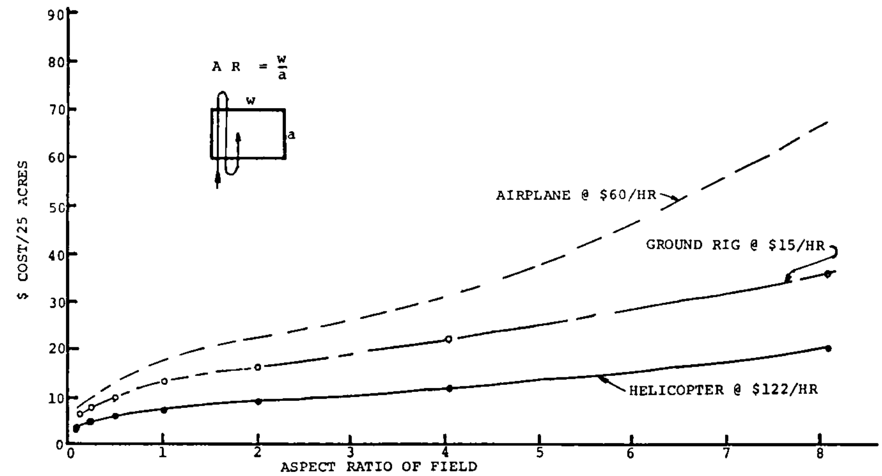


Figure 63. Cost to treat 25 acres vs aspect ratio of field.

COMPARISON PARAMETERS

	Helicopter	Airplane	Ground
Acres	25,100	25,100	25,100
Turn Time	12 Sec	40 Sec	200 Sec
Swath Length	Variable	Variable	Variable
Swath Width	100 ft	50	100
Vehicle Speed	80 mph	100 mph	8 mph

Field Aspect Ratio
- .125
- .25
- .5
- 1.0
- 2.0
- 4.0
- 8.0

Data were computed by the following:

$$AR = \frac{w}{a}$$

$$A = \frac{aw}{43,500}$$

$$N = \frac{w}{S}$$

$$t/pass = \frac{a}{V} + t$$

A = Number of acres

a = Swath length

w = Field length

N = Number of passes

t = Time/turn

s = Swath width

$$\text{Total Time} = \frac{w}{s}\left(\frac{a}{v} + t\right)$$

Total Cost = Total Time x Cost/Unit Time

$$\text{Cost} = \frac{w}{s} \left(\frac{a}{V} + t\right) \times \$/\text{Time}$$

At a low aspect ratio (AR < .5), the superior speed of the airplane more nearly compensates for its increased turn time over that of the helicopter. Turn time penalizes the airplane as the aspect ratio increases. The eight mile per hour speed for the ground rig is a practical maximum based on ground spraying tables. As these data do not include total duty cycle costs, they are for comparison purposes only but do reflect the speed/turn/swath width characteristic effects of the comparison.

Figure 64 shows the same treatment comparison for 100 acres (selected as approximating a maximum spray load). Treating four times the acreage changes the cost by a factor of about two for the various treatment methods. As these data do not include total duty-cycle costs they are for comparison purposes only but do reflect the speed/turn/swath width characteristic effects of the comparison.

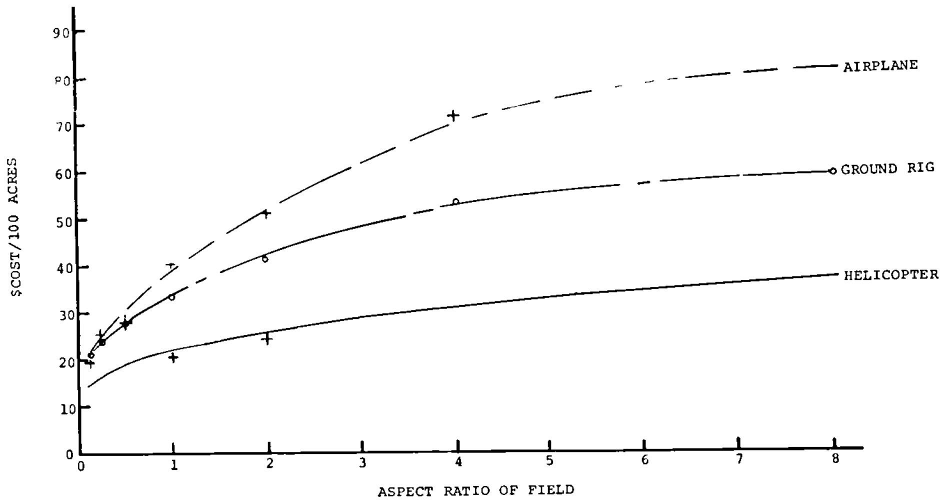


Figure 64. Cost to treat 100 acres vs aspect ratio of field.

Helicopter use within the field size framework evaluated herein (25 to 100 acres) appears to be the most effective from a cost viewpoint, based on flight time only, in comparing the three methodologies.

Data are presented in Tables 11, 12, and 13 for the comparison of the obsolescent (BHT Model 47) versus the new helicopter technology (BHT Model 206). A similar comparison for the BHT Model 206 versus a light Ag airplane for two altitudes of operation is also shown.

8.3 PRELIMINARY LAYOUTS - EQUIPMENT

Equipment selected for the computer analysis is based on the weight fractions evolved from the state-of-the-art evaluation (Figure 24). The selection of the equipment projected for this use is predicated on several assumptions:

- Fines control is assured by the use of special equipment. This results in no extra spray material needed for waste allowances.
- Nozzle development for this purpose will be continued until satisfactory fines control is achieved.
- Swath widths for liquid or solids dispersal are controllable up to 240 feet.
- Dispersal rates from 16 to 100 lb/acre are achieved by adjustability of apparatus.

Three methods of fines control were investigated - namely, nozzle droplet sizing, tip curtain, and inertia-separator boom. The methods of nozzle droplet size control to a particular micron diameter range were discussed in References 3, 6, and 7. Further work in this direction is needed for nozzle improvements but is beyond the scope of this study. The two alternate control means (tip curtain and inertia-separator boom) are based on methodologies from other disciplines. Air curtains are used for the separation of ambient atmospheres, i.e., for controlling paint contamination (humidity, dust, particles) in spray rooms, or for maintaining temperature control under differential conditions (air door). Figure 65 shows some of the potential design approaches in applying the air curtain to the tip of the boom. Pressured air, Figure 65(a), may be applied to a fan-shaped nozzle which would form the curtain. The nozzle directs the air curtain downward and aft to control the fines. Agglomeration of the fines particles by injected nucleating dusts may be used. The air curtains may also be formed by individual blowers mounted on the boom tips, Figure 65(b), which are powered by remote energy sources

TABLE 11. MODEL 47 TYPE VS BELL JETRANGER IN AERIAL APPLICATIONS (S.L.)

Assumptions:

Five (5) gallons per acre application rate. One-half mile swath length; 100-foot swath width.

Aircraft Characteristics:

	47 Type	Bell JetRanger
Chemical Load	90 Gal	150 Gal
Airspeed	60 MPH	80 MPH
Time to Turn	12 Sec	15 Sec
Ferry Distance	1/4 Mile	1/4 Mile
Spray Cycle		
Time in Swath (3 per load)	90 Sec	
Time in Turns	24 Sec	
Turn Around and Load	120 Sec	
Time in Swath (5 per load)		125 Sec
Time in Turns		60 Sec
Turn Around and Load		90 Sec
Total Time per Cycle	234.0 Sec	234.0 Sec
Area per Cycle	18.0 Acres	30.0 Acres
Cycles per Hour	15.4 Cycles	13.0 Cycles
Acres per Hour	176.0 Acres	392.7 Acres

TABLE 12. FIXED WING VS BELL JETRANGER IN AERIAL APPLICATIONS

Assumptions:

Five (5) gallons per acre application rate. One-half mile swath length.

Aircraft Characteristics:

	Fixed Wing	Bell JetRanger
Chemical Load	280 Gal	180 Gal
Airspeed	100 MPH	80 MPH
Swath Width	50 Ft	120 Ft
Time to Turn	40 Sec	12 Sec
Ferry Distance	5 Miles	1/4 Mile
Loading Time	4 Min	2 Min
Spray Cycle		
Time in Swath (18 per load)	5.4 Min	
Time in Turns	12.0 Min	
Turn Around and Load	10.0 Min	
Time in Swath (5 per load)		1.8 Min
Time in Turns		1.0 Min
Turn Around and Load		2.4 Min
Total Time per Cycle	27.4 Min	5.2 Min
Area per Cycle	56.0 Acres	36.0 Acres
Cycles per Hour	2.2 Cycles	11.5 Cycles
Acres per Hour	122.6 Acres	415.0 Acres

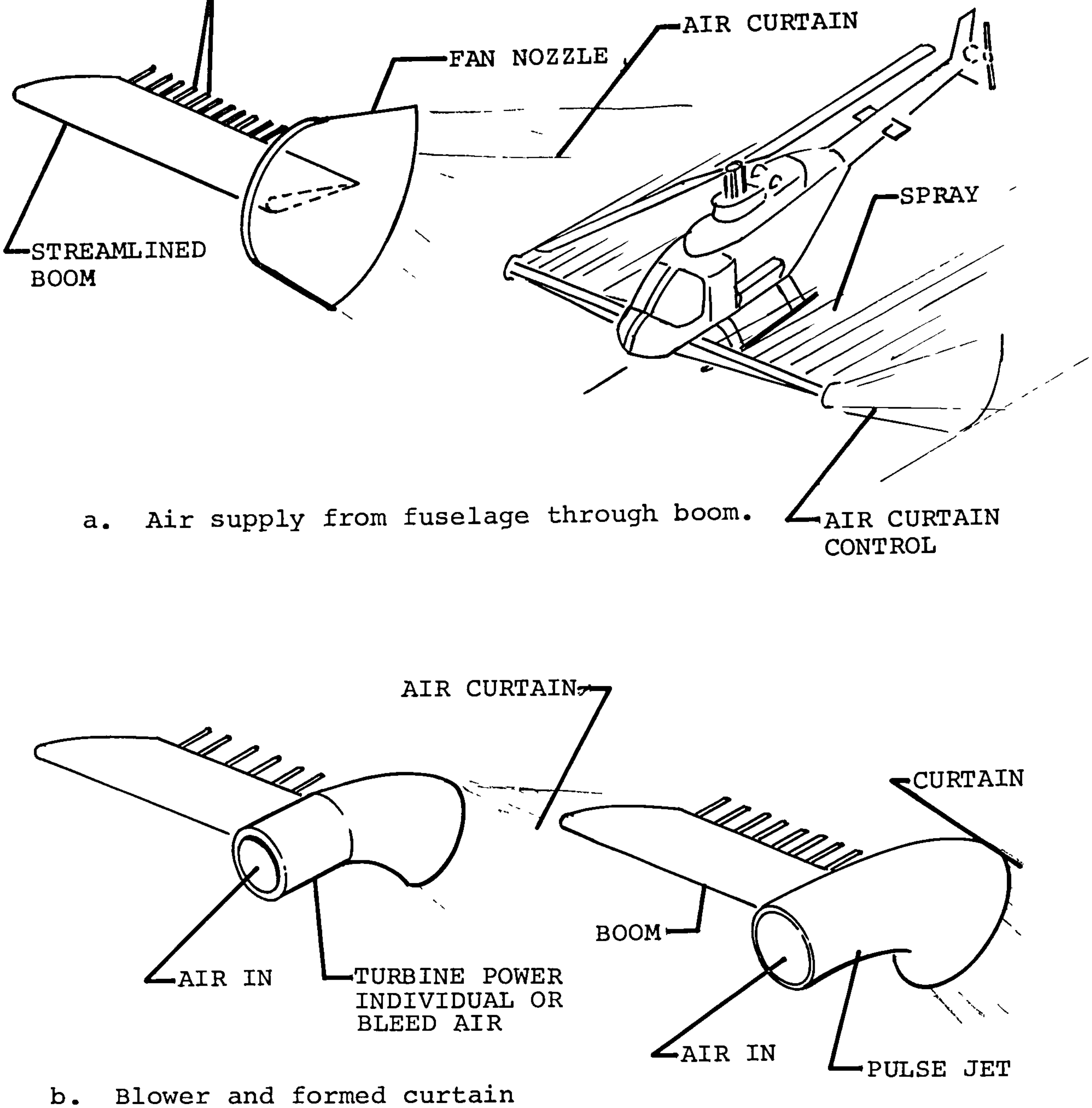
TABLE 13. LIGHT FIXED WING VS BELL JETRANGER IN AERIAL APPLICATIONS (ALTITUDE)

Assumptions:

Four (4) gallons per acre application rate. One-half mile swath length; altitude 6,000-ft; temperature 80°F.

Aircraft Characteristics:

	Light Fixed Wing	Bell JetRanger
Chemical Load	130 Gal	122 Gal
Airspeed	100 MPH	80 MPH
Swath Width	50 Ft	100 Ft
Time to Turn	40 Sec	12 Sec
Ferry Distance	5 Miles	1/4 Mile
Loading Time	4 Min	2 Min
Spray Cycle		
Time in Swath (10 per cycle)	3.0 Min	
Time in Turns	6.7 Min	
Turn Around and Load	10.0 Min	
Time in Swath (5 per cycle)		1.9 Min
Time in Turns		1.0 Min
Turn Around and Load		2.4 Min
Total Time per cycle	19.7 Min	5.3 Min
Area per Cycle	30.3 Acres	30.4 Acres
Cycles per Hour	2.5 Cycles	11.1 Cycles
Acres per Hour	100.0 Acres	337.0 Acres



a. Air supply from fuselage through boom.

b. Blower and formed curtain

c. Pulsejet curtain

Figure 65. Air curtain control of fines.

such as helicopter engine hydraulic power takeoffs, bleed air turbines, or by alternatives such as integral blower/power plants (reciprocating engines, turbines, pulse jets).

Figure 66 shows possible approaches to the inertia separator boom which may be used to vacuum the fines from the ejected spray to be returned to the reservoir for recycling through the nozzles. It may be noted that an ejector based on bleed air use, air pumps, or blowers is needed to generate the fines separation flow. Partial scrubbing of the fines from the air and recovery of their volume may be achieved by a single return plenum, Figure 66(a), and the double-return plenum, Figure 66(b), which could be expected to achieve a higher recovery rate.

Drag of a dual inertia-separator spray boom is expected to be higher than that of the single unit; however, the approximate 30 percent increase in load effectiveness by controlling the fines tends to be offsetting.

The propulsive effects of a tip curtain/jet device may offer some advantages in overall aircraft/boom design. Auxiliary propulsion of a helicopter tends to reduce the magnitude of the rotor inflow in that the rotor tip path plane is flown substantially parallel to the aircraft flight path. Translational velocity components of a tilt-rotor helicopter form a major portion of the wake at high forward flight speeds where induced downwash velocities are small because of the large masses of air treated by the rotor. Establishment of possible use of this aircraft with its low downwash velocity for practical applications of dispersal materials should be investigated.

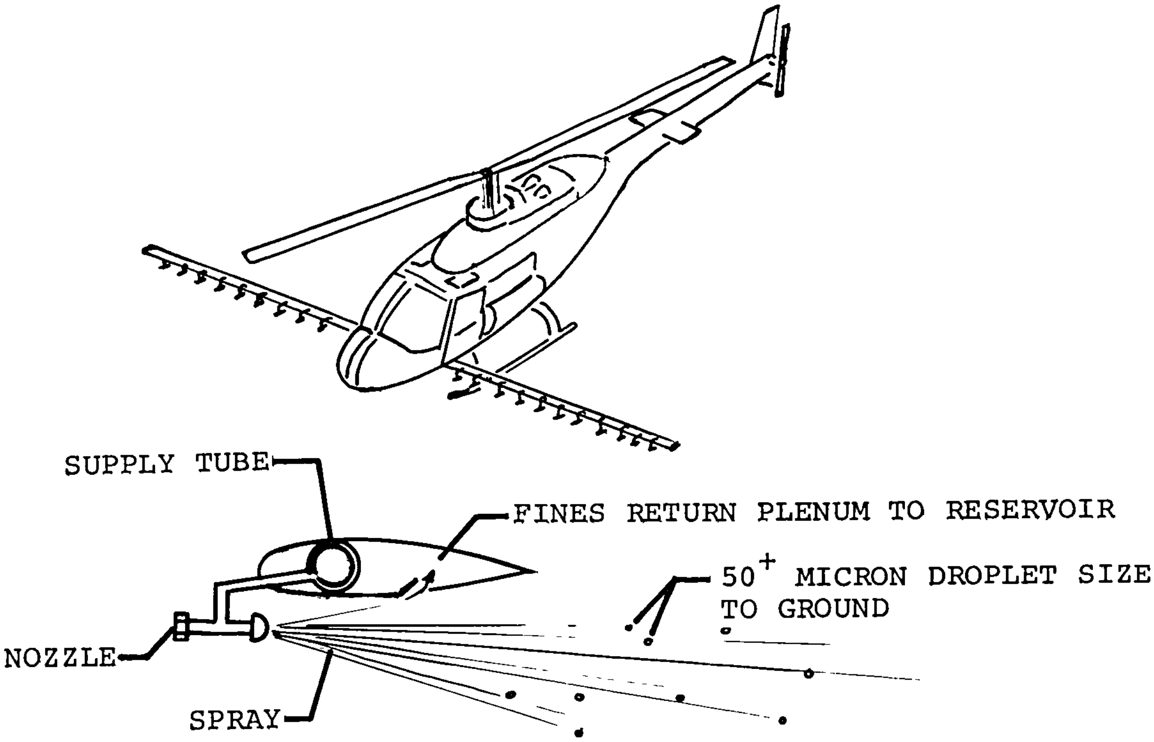
8.4 ENVIRONMENTAL EFFECTS ON COMPOSITES AND PLASTICS

Environments are classified as natural and service induced.

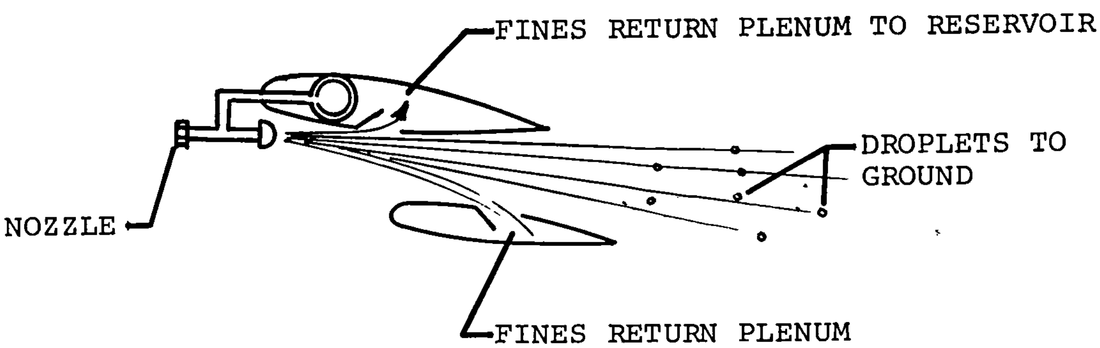
- Natural environments include humidity, temperature, rain, ice, ultraviolet radiation, etc.

- Service-induced environmental factors are erosion, abrasion, service fluids, and agricultural chemicals.

The effect of temperature/humidity on composite components is quite different from that on metal structures. There are not appreciable effects which are comparable to corrosion; however, the composite structures absorb moisture when subjected to high humidity environmental effects. The matrix material undergoes a reversible change in properties as a result of this moisture absorption. The change in properties is not great and can easily be accounted for in design of the structures unless there is a coincidental exposure to temperature



a. Single separator plenum



b. Double separator plenum

Figure 66. Inertia separator booms

close to the heat distortion temperature of the material. Proper choice of the matrix material will minimize this problem. Exposure to low temperatures has no deleterious effect on composite parts unless an elastomeric material is used.

Ultraviolet radiation (exposure to sunlight) can cause degradation of organic materials if they are not protected. Glass and graphite fibers, being inorganic, are unaffected by this radiation. There is some effect on Kevlar (Aramid) fibers; however, such parts may be screened from the effect of ultraviolet radiation by various means, such as, sunscreen materials in the matrix system and by the ordinary protection offered by paint or other exterior finish materials.

All the effects of natural environmental exposures on composite parts can be mitigated or eliminated by the maintenance of a good finish system on the structure.

Service-induced environmental effects on composite structures can be deleterious to the aircraft in two ways. One of the primary effects of erosion and abrasion is the destruction of the helicopter finish system. It is also possible that some of the agricultural chemicals dispensed by the Ag aircraft, if not thoroughly removed as soon after exposure as possible, could have a very destructive effect on organic finishes.

In general, the chemicals used for agricultural purposes do not seriously affect composite materials, particularly the dry chemicals used. Liquid sprays can constitute a more severe problem, especially those which are diluted with various petroleum products. The petroleum distillates used for this purpose can cause serious problems on the resin matrix material of composites, as well as on plastic transparencies normally used in helicopters. Because the petroleum distillates are generally not carefully controlled as to composition, it is possible on occasion to get an aromatic solvent which is severe in its effect on organic materials. Here again, the maintenance of the finish system is important in minimizing these effects. Proper design of the aircraft emphasizes elimination of pockets and crevices which could trap chemical powders or solutions. This condition involves both internal and external traps. Undrained, internal pockets are undesirable since they accumulate and retain materials making the structural effects more severe.

In general, composite materials have the capability to provide a more durable and serviceable structure than metallic structures for agricultural helicopters.

8.5 POWER PLANT TRADEOFF SELECTION

The Ag helicopter computer synthesis program has typical data available for turbine engines of various sizes (specific engines or rubberized). Thus, selection of aircraft power required may be based on the needs of the aircraft by either approach. Dispersal power is estimated as follows:

- For a pod system with its own integral power plant, the helicopter engine power requirement is increased by the need to lift the delta weight of the pod engine and its support systems. For a 10 horsepower dispersal unit (common size design), this represents about 30 pounds of engine installation weight, or at a rotor 10 lb/hp lifting capacity an extra 3 horsepower. Based on a helicopter with installed power of 300 horsepower, this represents only 1 percent. This is considered a negligible value insofar as its effect on the helicopter mission performance is concerned.

- An extraction of 10 horsepower from the turbine engine reduces the power available but represents a power loss based on 300 installed horsepower of only 3.3 percent. With an efficient mechanical drive to the dispersal pump system (98 percent estimated efficiency) and use at moderate spray speeds where excess power is near a maximum, negligible performance losses would exist.

These horsepowers are low enough that the factors of fuel tankage, amount of fuel, etc., related to utilizing engine power become obscured i.e., fuel for the mission is added at each spray tank fill and represents a percentage of the maximum tankage capacity.

8.6 TRADEOFF SENSITIVITY

Tradeoff sensitivity evaluations were conducted for the selection of the aircraft of this study in the following manner.

- Basic sizing was established arbitrarily by aircraft gross weight selections to be evaluated in the ratio of 1, 2, and 4.

- The effects of rotor solidity ratio variations on required aircraft power were additionally evaluated per Section 7.3.7.

- Various rotor diameters for the 6000-pound gross weight aircraft were studied by the evaluation of the flight time needed to accomplish Mission A, i.e., the aircraft with the least required flight time to perform the mission based on rotor diameter variation was selected for the economic comparisons.

- RPM effects for the 3000-pound special in hovering and forward flight were evaluated to determine possible improvements in the required power through rotor optimization. Variations in the rotor tip speed for the various missions indicated that a value of about 700 ft/sec provided near-optimum performance.

- Factors were established to modify the weight or power inputs. These were applied to the cases as shown in Table 7-III to modify the characteristics of the helicopter. Comparison of the figures in Section 8.9 indicates the sensitivity effects of changing the swath widths, dispersal rates, and gross weights of the helicopters for the three noted missions.

8.7 FEDERAL REGULATION CONFORMITY

A review of the Federal Air Regulations (FAR) relating to the helicopter designs of this study for the impact of their applicability to Ag helicopters indicates the following:

- FAR basic requirements are organized to ensure the safety of the public, pilots and possible passengers in the aircraft. When special flight conditions exist, these requirements may be altered for the particularly pertinent situation. Such has been the case for many years as with the Pilatus TurboPorter airplane when used in industrial applications, i.e., the normal general aviation 4750-pound gross weight may be exceeded by flying at 6200 pounds. This naturally results in an increase in loads and a reduction in allowable flight load factors but with increased utility. Of course, adequate stability and controllability must be demonstrated under these conditions.

- In general, it may be stated that any relaxation of required utility aircraft load factors on piston-powered helicopters would be marginally beneficial because of the engine power situation. As the maximum available power is normally limited by engine capabilities, no extra available load-lifting capacity of the vehicle exists. Aircraft stability and flight controllability are also limiting factors.

  For turbine-powered helicopters this is not normally the case, for example, much excess power may be available and the limitations may be associated with other components, such as the rotor, by stability and control or transmission capability. For Ag use, Section 7.3.7 describes the rotor differences and Section 7.3.5 discusses needed stability and control devices. Special regulation requirements for rapid load dumping, bendable booms, equipment functioning (nonleakage shutoff), flight operational techniques, and other areas are in order. These may be defined in accordance with the use of the aircraft, i.e., for passenger-carrying or utility helicopters used in Ag work. All the standard regulations would naturally be applied in producing the designs. When this type aircraft is used for Ag purposes, overload gross weights are established as with the Turbo-Porter based on the characteristics of the particular aircraft.

For the special Ag aircraft designs based on standard components, as shown in this study, it would appear that large increases in performance are available if payloads could be doubled over standard utility values. To achieve this, regulations based on the weighted load factor approach might be in order when variable stability and controllability are used (reference Section 7.3.5), i.e., high load factors occur only in maneuvers during high gross weight takeoff and before dispersal starts. Accelerations during these conditions could be limited. When one half of the dispersed material and fuel is gone, the load factors then approximate those of the standard utility helicopter.

- Environmental regulations on noise and engine exhaust product pollution (FAR 36 and EPA 87) have not as yet been fully applied for helicopters; therefore, their impact is not as yet known. However, from the discussion of Section 7.3.12 it would appear to be based on the type of approach taken by the engine manufacturer.

- For special new design Ag aircraft, the requirements might be relaxed where there is a single-purpose one-man vehicle with operational conditions that may be strictly limited, i.e., spraying or solids dispersal usually occur in wind conditions of less than 15 mph and gust encounters at 100 mph are relatively rare. The "g" maneuvers at takeoff prior to dispersal might be sharply limited. Meters or heads-up displays to advise the pilot makes this an attractive situation. It could be expected that regulation of this type vehicle could be relaxed to be somewhere between that of the nonpassenger-carrying experimental aircraft and the utility helicopter. Safety of the pilot and the public must be ensured. For the Ag specials, this appears possible at a lower level of regulation than for utility helicopters.

8.8 POWER FOR DISPERSAL EQUIPMENT

The following possibilities exist for dispersal equipment power.

- Reciprocating engine - air or water cooled
  - Gasoline
  - Diesel
- Rotary engine
  - Gasoline
  - Diesel
- Gas turbine
- Air turbine
  - Air supply from aircraft APU or engine bleed
  - Air windmill
- Turbine engine jet fuel starter (such as Model STU-26/A JFS)
- Electric motor
  - Battery
  - Power cell
- Power takeoff - helicopter power plant

For coupling of these power sources with the driven member (pumps, mechanical spreaders, others), there are four power transmission possibilities. They are rated in increasing order of weight and with their normally expected values of efficiency as follows:

Possibilities	Efficiency Percent
Pneumatic pump and motor (air turbine)	60
Mechanical means - shafting, clutches, gears, etc.	95
Hydraulic pump and motor	80
Electrical generator (alternator) and motor	90

Contemporary electrical power generation and transmission equipment for this purpose tends to be heavy, although widely used. New magnetic materials which may permit much lower generator and motor weights are now being investigated. The use of power cells is probably precluded because of the state of development. Combinations of reciprocating or rotary-type engines with a pneumatic transmission appear unduly complex and inefficient based on previous experience. Possible power sources, therefore, appear as follows:

- Air Drive
  - Air windmill
  - Gas turbine bleed aircraft power plant
  - APU
- Mechanical drive
  - Reciprocating
  - Rotary
  - Gas turbine
  - Jet fuel starter
- Hydraulic/electrical drive
  - Reciprocating
  - Rotary
  - Gas turbine
  - Jet fuel starter

The availability of the above in a size range suitable for use will guide the selection of a practical power plant.

8.8.1 <u>Application of Power Plant System</u>

The selection of a particular power plant/transmission system is normally made through a matching of the engine loading requirements and the characteristics of the power plant system. For example, the reciprocating engine requires a clutch, gearing, and transmission shafting to adjust power output at a particular RPM to the load characteristics. With air or fluid pumps, the horsepower required normally varies as the cube of the rotative speed; therefore, starting under low load is similar to the airplane propeller/engine combination.

Consideration of the characteristics of the rotary engine, the air turbine, the gas turbine, or the jet fuel starter for powering dispersal equipment indicate the following:

- Rotary engine - rotor-seal wear resulting in a short overhaul life limits the use of this engine. To date, pollution effects have also retarded general acceptance.
- The air windmill (propeller drive) has been widely used on airplanes because of the lack of a suitable power takeoff on the engine. It suffers from a poor conversion of free stream energy to power (25 percent to 40 percent efficiency), a limited capacity (less than 7 horsepower with present day installation), and may cause high interference drag effects on the aircraft.
- Although not all sizes of gas turbines suitable for pumping presently exist; of those that do, the initial cost is such as to preclude use on dispersal equipment. Rather, lower cost, industrial-type reciprocating engines (Briggs and Stratton - 10 hp, Volkswagon - 50 hp) are used on present equipment. A low required number of these special-use turbines precludes a specific development from a cost viewpoint.
- The jet fuel starter may be considered similarly. From the above, the viable power drive alternatives are the following:
    - Reciprocating engine
        - Mechanical drive
        - Hydraulic drive
    - Airbleed turbine engine
        - Pneumatic drive
    - Power takeoff - helicopter transmission
        - Electrical
        - Hydraulic
        - Mechanical

8.8.2 Power Required to Disperse Materials

Spray

Flow Rate:

$$F_R = \frac{SrV_w}{495} \text{ gal/min}$$

where:

S = Swath Width, ft

r = gal/acre

$V_w = V_{working}$ = Aircraft speed, mph

Horsepower Required: (Reference 12)

$$HP = \frac{QdH}{550\eta}$$

where: Q = cu ft/sec

d = fluid density, lb/cu ft

$$\text{if } H = \frac{p}{.433} \quad \text{(Ref 12)}$$

H = height of head, ft

η = pump system efficiency, decimal

$$HP_R = \frac{Qdp}{238\eta}$$

p = pressure in lb/sq in

$$k = \frac{(62.4)231}{1728} = 8.35 \text{ lb/gal}$$

$$F_R = Q \times d \times \frac{1}{k}$$

$$F_R = Q \times d \times \frac{1}{8.35} \times 60$$

$$Qd = \frac{F_R}{7.16}$$

$$HP_R = \frac{F_R p}{(7.16)(238)} = \frac{F_R p}{1711\eta}$$

$$HP_R = \frac{SrV_{working} \times p}{(495)(1711)\eta}$$

$$HP_R = \frac{SrV_w p}{8.5 \times 10^5 \eta}$$

Example:
for

$S = 100$ ft
$r = 3$ gal/acre
$V_w = 60$ mph
$\eta = .25$
$p = 60$ psi

$$HP = \frac{(100)(3)(60)(60)}{.85 \times 10^5 \; (.25)}$$

$$HP = 5.06$$

8.8.3 WINDMILL POWER

Windmill-powered generators to pulverize, transfer, agitate, pump, or produce electricity for pumps have been used on airplanes for many years. Such systems eliminate an engine-driven generator and its electrical system. However, its inefficiency (losses by parasite drag and in conversion of wind power to electricity) plus sensitivity to airspeed and load (brake required for zero-load condition to prevent over-speed) tends to preclude use on a modern system.

Its power generating capability may be expressed as follows (Reference 12):

$$HP = C_p \, D^2 \, V^3$$

Where:

C_p = Power Coefficient
= .70 to .2 x 10^{-6}

For a 1 ft dia fan at 100 mph:

$$HP = (.5)(1)^2(100 \times 1.467)^3(10)^{-6}$$
$$= 1.57$$

If the efficiency of converting the energy in the air to mechanical power is 40 percent (windmill), the air velocity is generated at a 70 percent efficiency (airplane propeller), and an electrical generator/motor system (70 percent efficiency) is used to absorb and distribute the power. The effective power for dispersal is:

$$\text{Available hp} = (1.57)(.40)(.70)(.70) = .308$$

If the windmill powers a hydraulic pump/motor combination, the transmission efficiency would be similar to the electrical drive.

$$\text{Efficiency} = \frac{.308}{1.57} \times 100 = 19.65\%$$

This does not include any increases in either parasite or interference drag from electric motors, brake housings, or support structure on the aircraft. These could require increased engine power to maintain flight speed. If .25 square feet is a representative value of this, the equivalent horsepower is:

$$hp = \frac{DV}{375} \qquad \text{Where: } D = \frac{1}{2} C_D \rho \, SV^2$$

$$= \frac{(12.7(100)}{375} \qquad = \frac{1}{2}(1.0)(.002378)(.25)(146.7)^2$$

$$= 1.76 \text{ hp} \qquad = 12.7 \text{ lb}$$

The efficiency then equals:

$$E = \frac{.308 \times 100}{1.57 + 1.76} = \frac{.308 \times 100}{3.33} = 9.25\%$$

8.9 ECONOMIC ANALYSIS

Two prime factors to estimate the cost of performing the mission of Operators A, B, and C are the cost per hour of operation (reference Section 2) and the flight time to complete the mission for each size of helicopter. The cost of operation per hour of flight time is plotted versus the gross weight of the aircraft as determined from the state-of-the-art parts of this study (Figure 67). As may be noted on the figure, the estimated minimum and maximum costing is indicated. In the state-of-the-art estimations of costs, it was noted that evaluation of the effects of wear and tear on spraying and other dispersal equipment is difficult. Differences between the service life of equipment, the scope of the equipment capability, replacement costs of components, wear and tear, and other equipment service charges do not lend themselve to ready comparative evaluations. Therefore, several typical detailed equipment use situations were reviewed and it was decided to select a cost/hour value as halfway between the estimated minimum and maximum curves as typical for use in the computer programs. The flight times to complete the missions were output from the computer.

Input data for a 3000-, 6000-, and 12000-pound aircraft included the following:

- Dispersal rates are 16, 32, and 100 lb/acre

- Swath widths were varied from 80 to 240 feet as follows:

For spraying

Aircraft Gross Weight, lb	Swath Width, ft
3000	80
6000	120
12000	180

For Solids Dispersal

3000	200	120	180
6000	200	180	200
12000	200	240	240

Synthesis of the helicopters was based on the weight and performance parameter relationships established for the computer programs. Typical data printouts of the evaluated vehicles are included as Appendix D.

Data on the configurations selected by case number from Table 10 are shown in Figures 68, 69, and 70. Plotted is the cost/hectare (cost/acre) versus the gross weight of the studied aircraft performing three missions for dispersal rates of 16, 32, and 100 lb/acre. Costs to perform a particular mission using a different size helicopter may be noted from these curves as well as the cost effects of performing various missions by a particular gross weight aircraft. Variations in vehicle assumption (Section 7.3.13) are indicated by the case

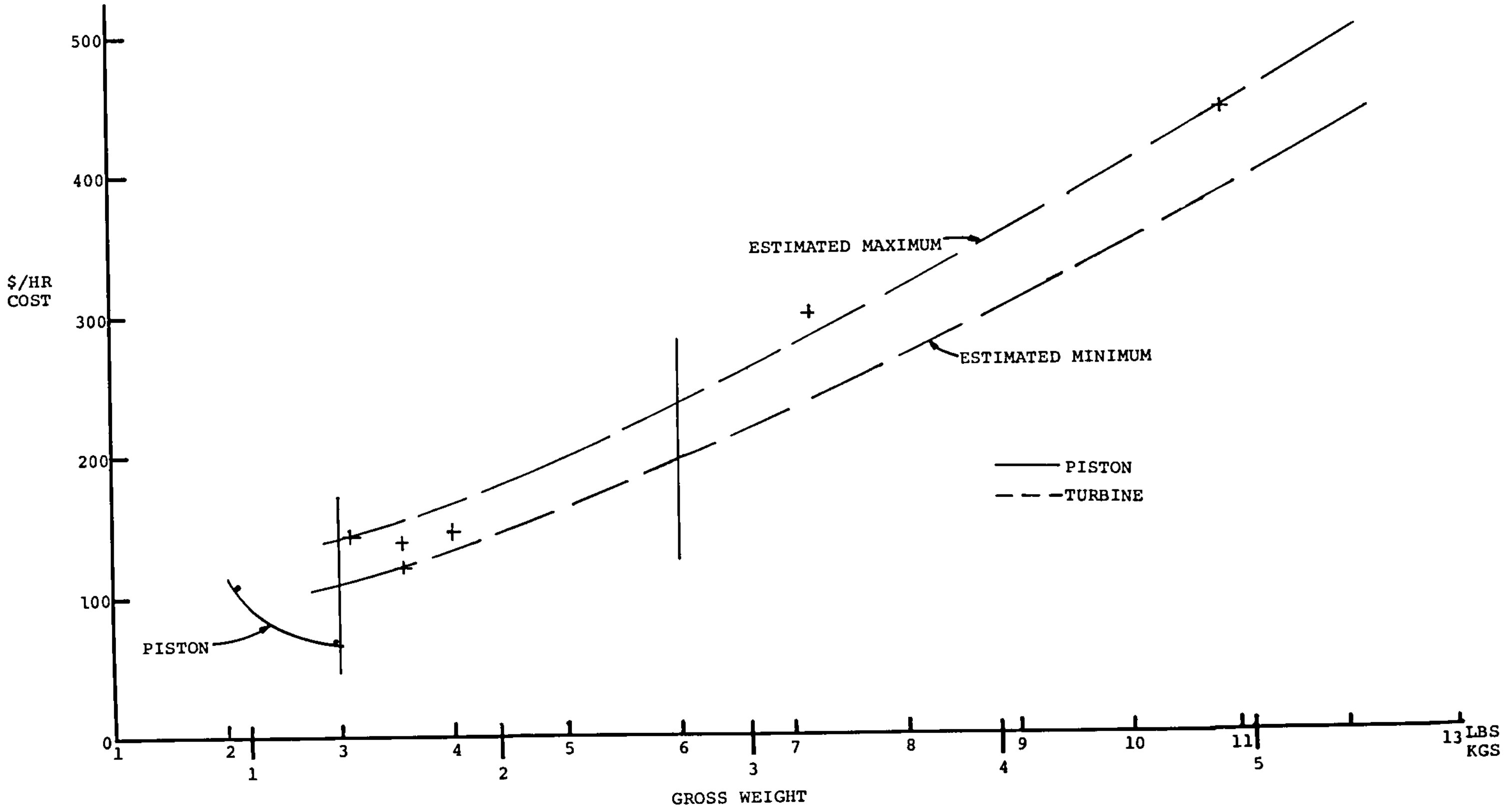


Figure 67. Cost/hour operation vs gross weight based on 600 hour/year operating time.

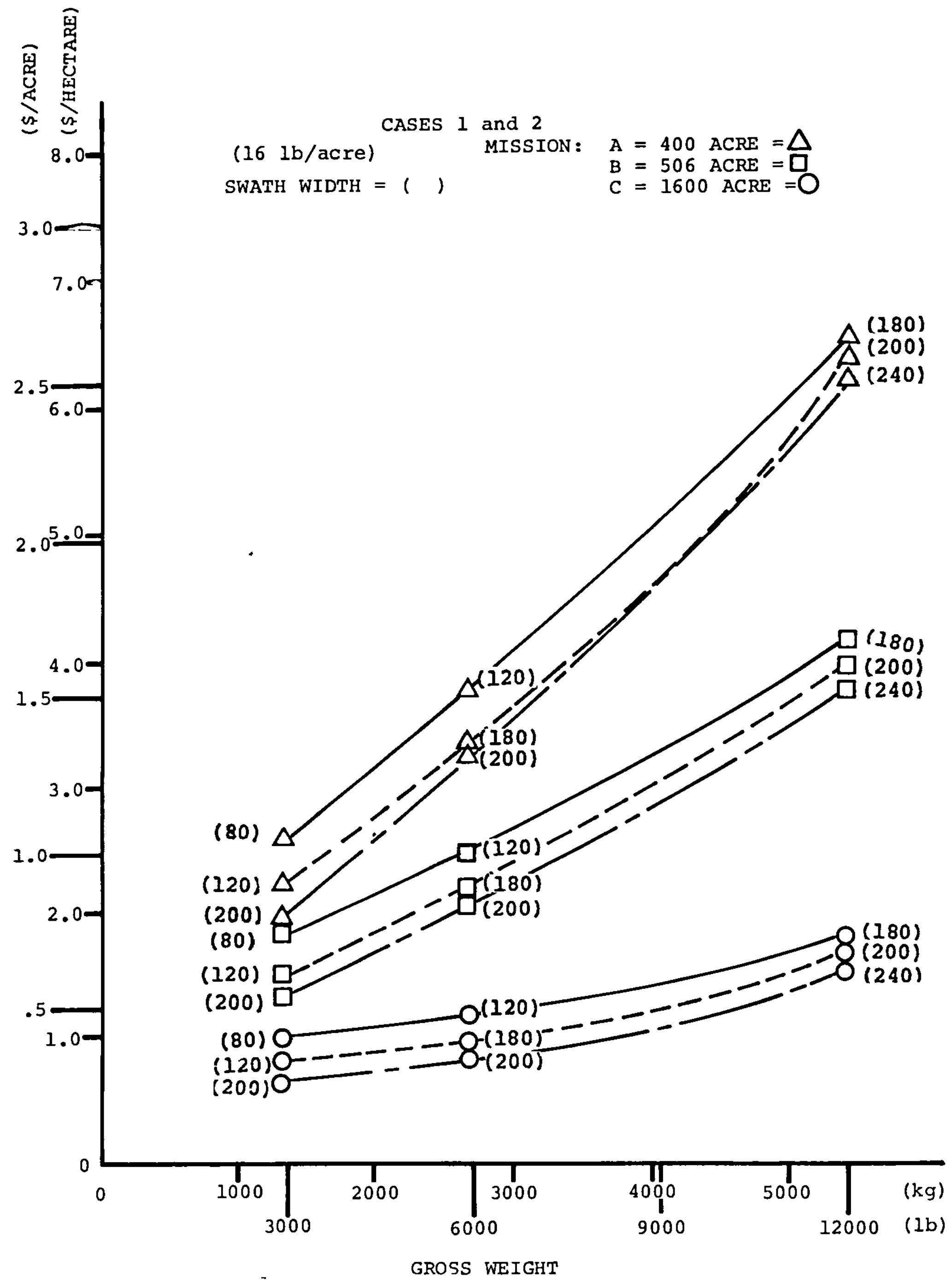


Figure 68. Cost/acre vs gross weight.

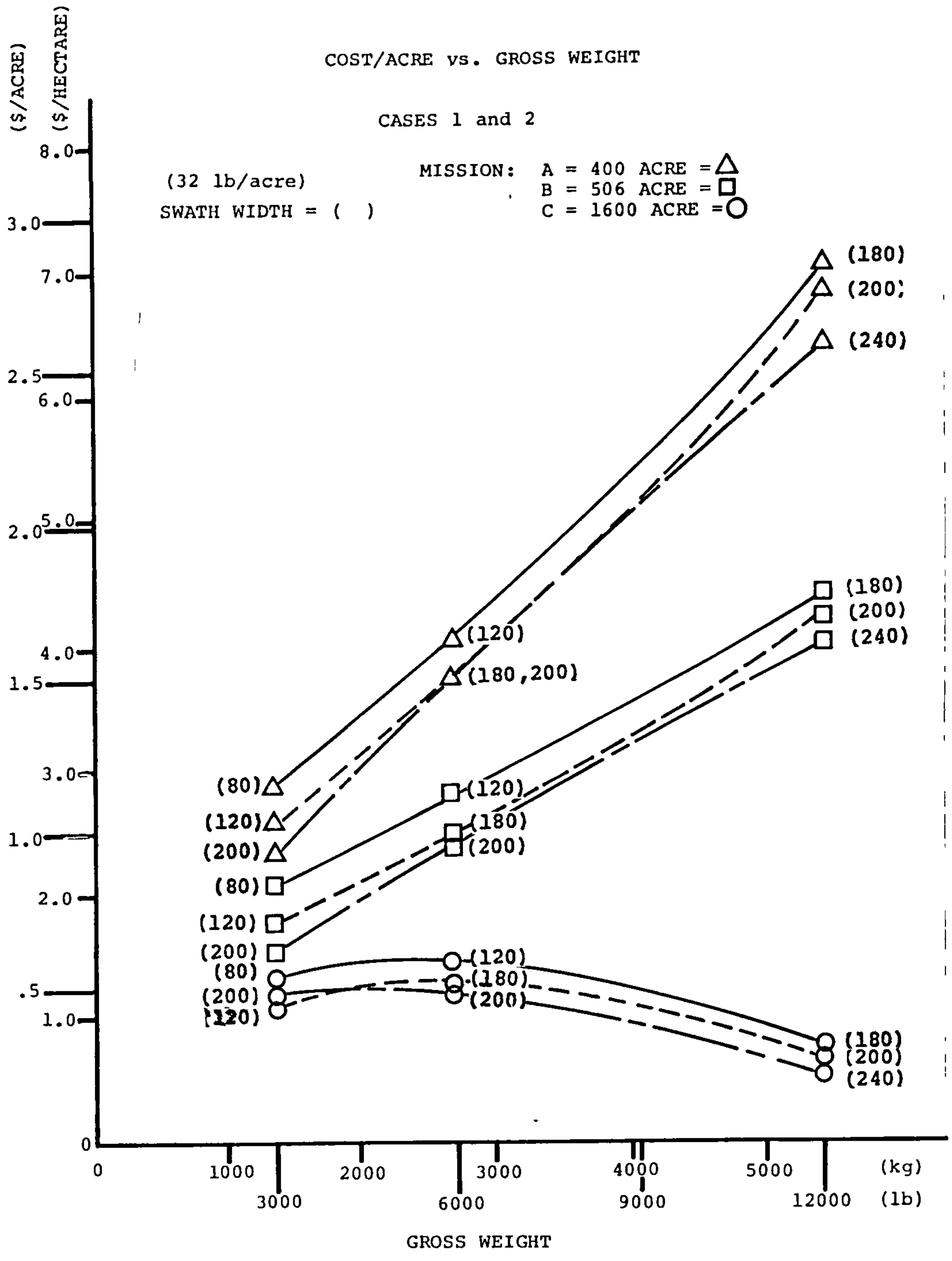


Figure 69. Cost/acre vs gross weight.

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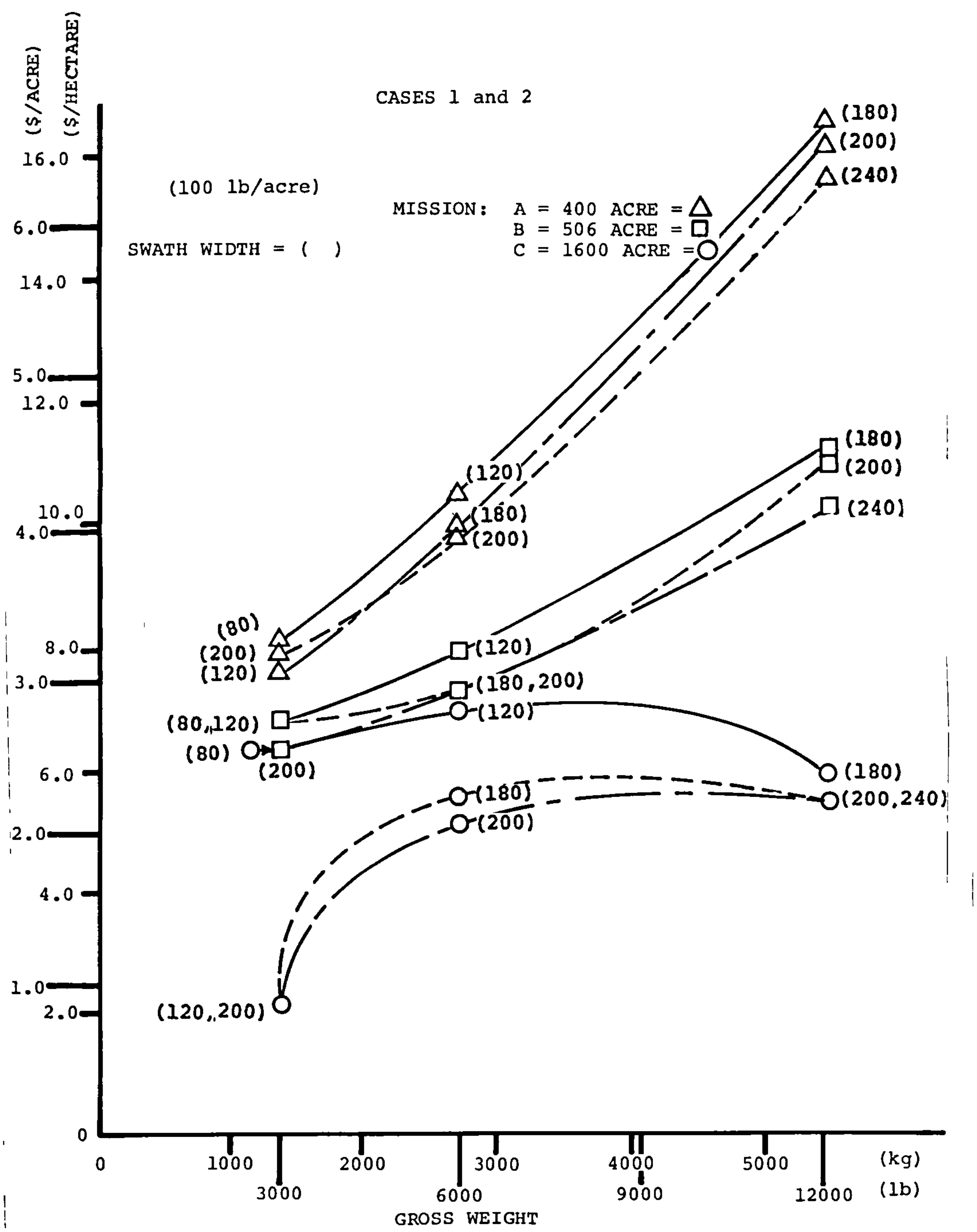

Figure 70. Cost/acre vs gross weight.

number of the plots. Cross reference of Figures 68, 69, and 70 gives comparisons of the effects of dispersal rates and swath widths. For the 120-foot swath width example from Figure 68 (16 lb/acre), the 3000-pound gross weight cost is $.90/acre; from Figure 69 (32 lb/acre), it is $1.05/ acre; and from Figure 70 (100 lb/acre), the cost is about $3.05/acre.

Trends shown in these figures reflect the following:

- Costs for the smaller dispersal rates (16 and 32 lb/acre) are lower with all missions using the lighter gross weight helicopters.

- Increasing the number of acres treated for a particular size vehicle reduces the cost/acre.

- For a high rate coverage (100 lb/acre) and the large area missions the heavier helicopter tends to be more effective.

It may be noted that cases 1 and 2 reflect the contemporary turbine-powered helicopter and its 1985 version with the various Ag study evolved features added to make a safe, comfortable, and more forgiving helicopter.

Case 3 of Figure 71 shows the effects of only favorable modifications to the 1985 aircraft. Trends tend to be similar to the earlier cases with the heavier aircraft being more effective at the extreme dispersal rates (100 lb/acre).

Case 4 shows the effect of the use of standard components on Ag specials in Figure 72. For the 3000-pound gross weight aircraft with an 80 foot swath width and 16 lb/acre rate, the cost per acre for Mission A is reduced from $1.10 to about $1.00. Again, sizing of the aircraft to the dispersal rate indicates higher effectivity at the 100 lb/acre value.

Case 5 (Figure 73), using only the favorable modification, shows trends similar to those of case 4 with small changes in cost values. Case 6, the new Ag specials (Figure 74), appear to have similar data to the aircraft of case 4 as do those of case 7 (Figure 75). However, differences do exist in the middle range 6000-pound gross weight helicopter sizes for the heavy dispersal rates.

Review of the above indicates that for modest dispersal rates and low acreage small helicopters can most readily achieve the mission. For higher dispersal rates and larger areas, bigger aircraft would be more effective. A viable economic concept becomes the choice between a small aircraft fleet, a few large vehicles, or a mix of sizes based on the characteristics of the particular operator need.

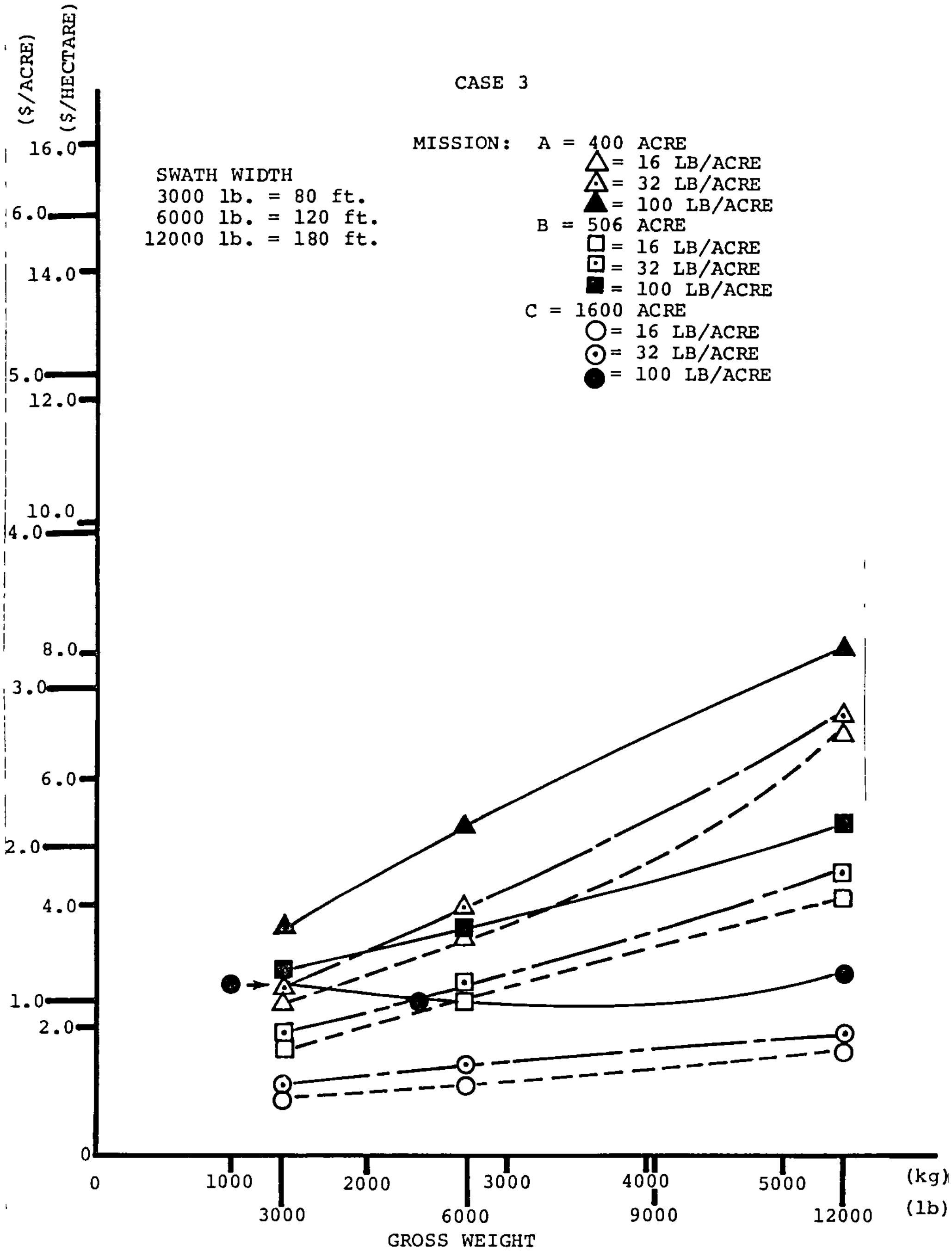

Figure 71. Cost/acre vs gross weight.

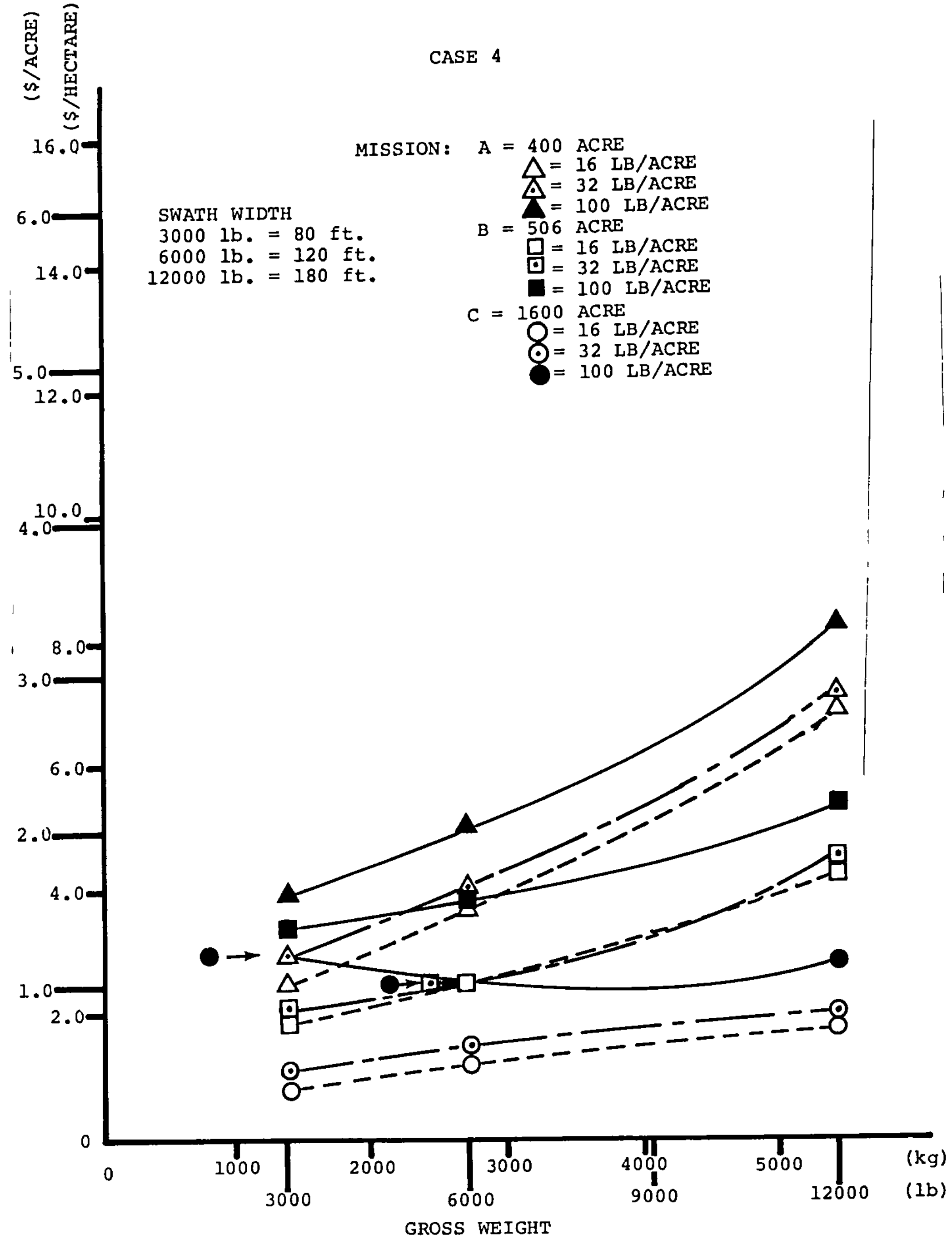

Figure 72. Cost/acre vs gross weight.

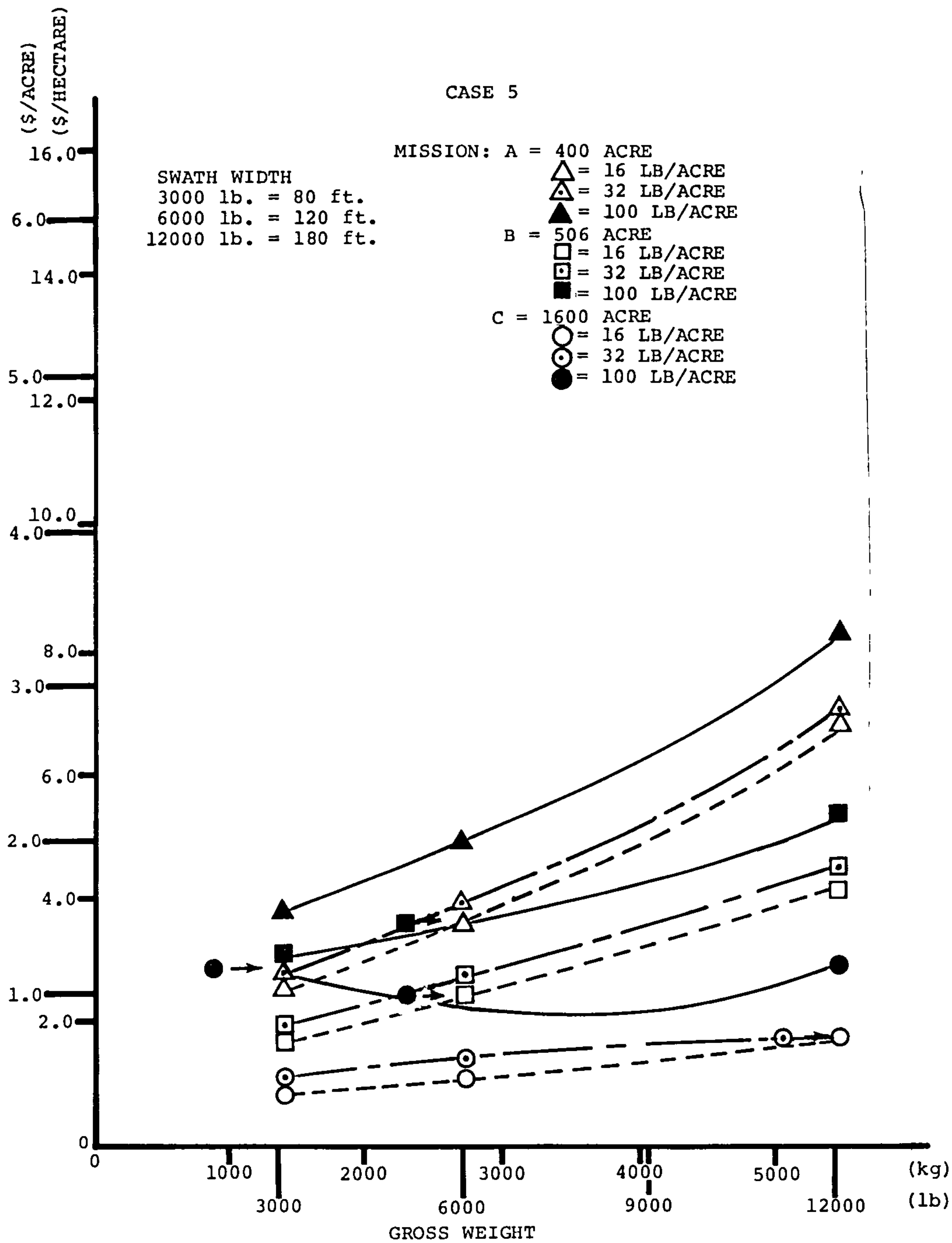

Figure 73. Cost/acre vs gross weight.

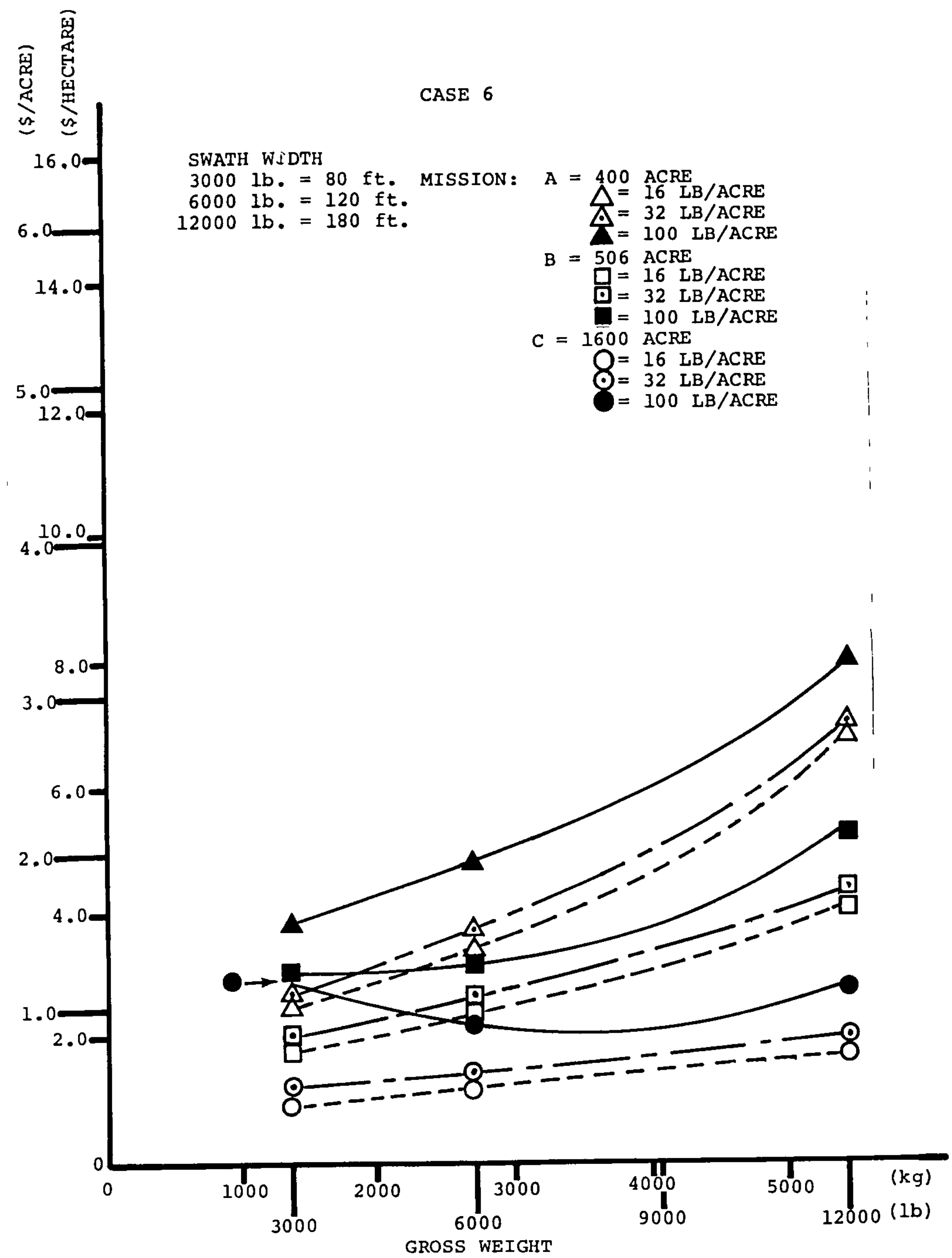

Figure 74. Cost/acre vs gross weight.

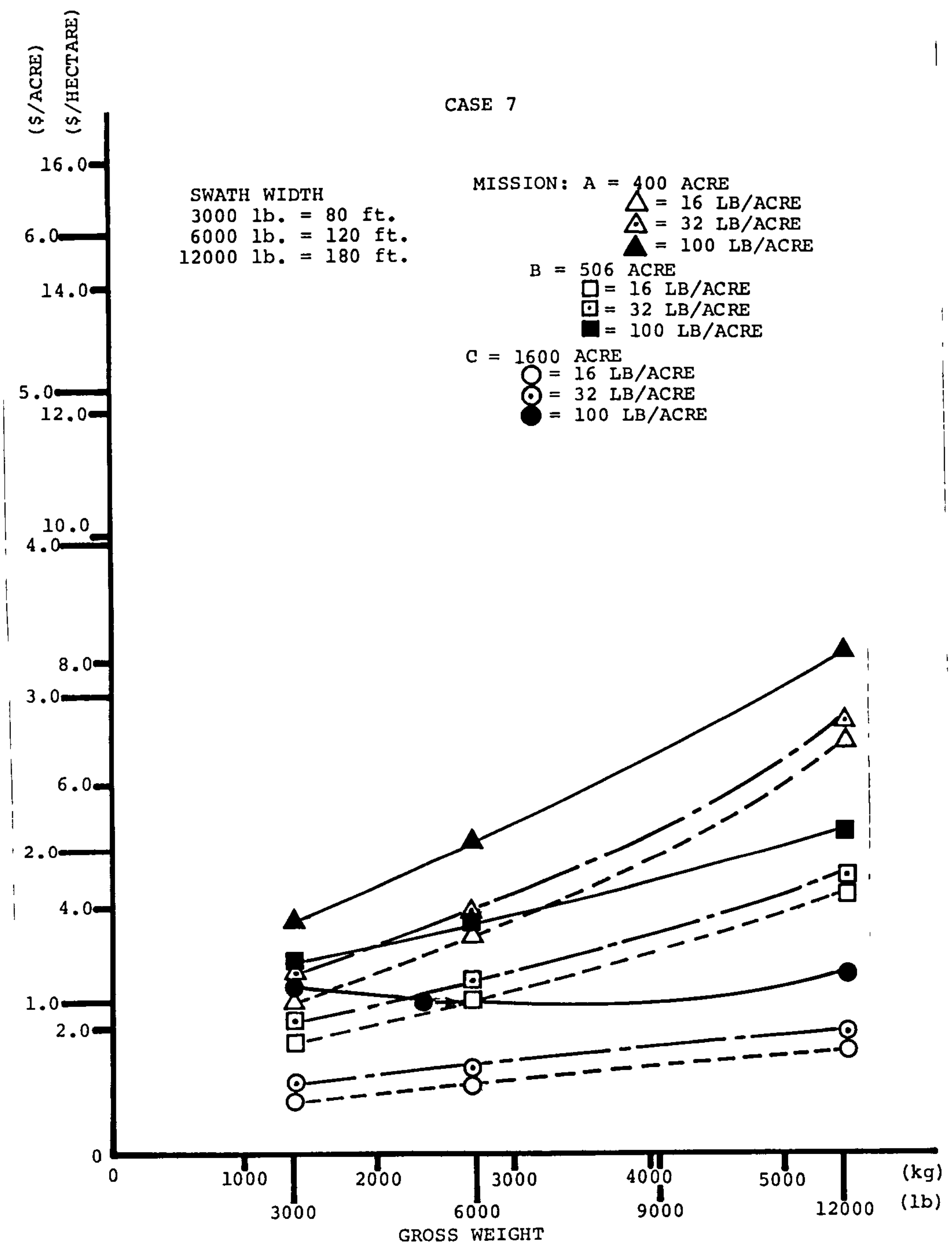

Figure 75. Cost/acre vs gross weight.

8.10 STUDY PLAN

Figure 76 is a morphological chart of the computer study plan used in this evaluation.

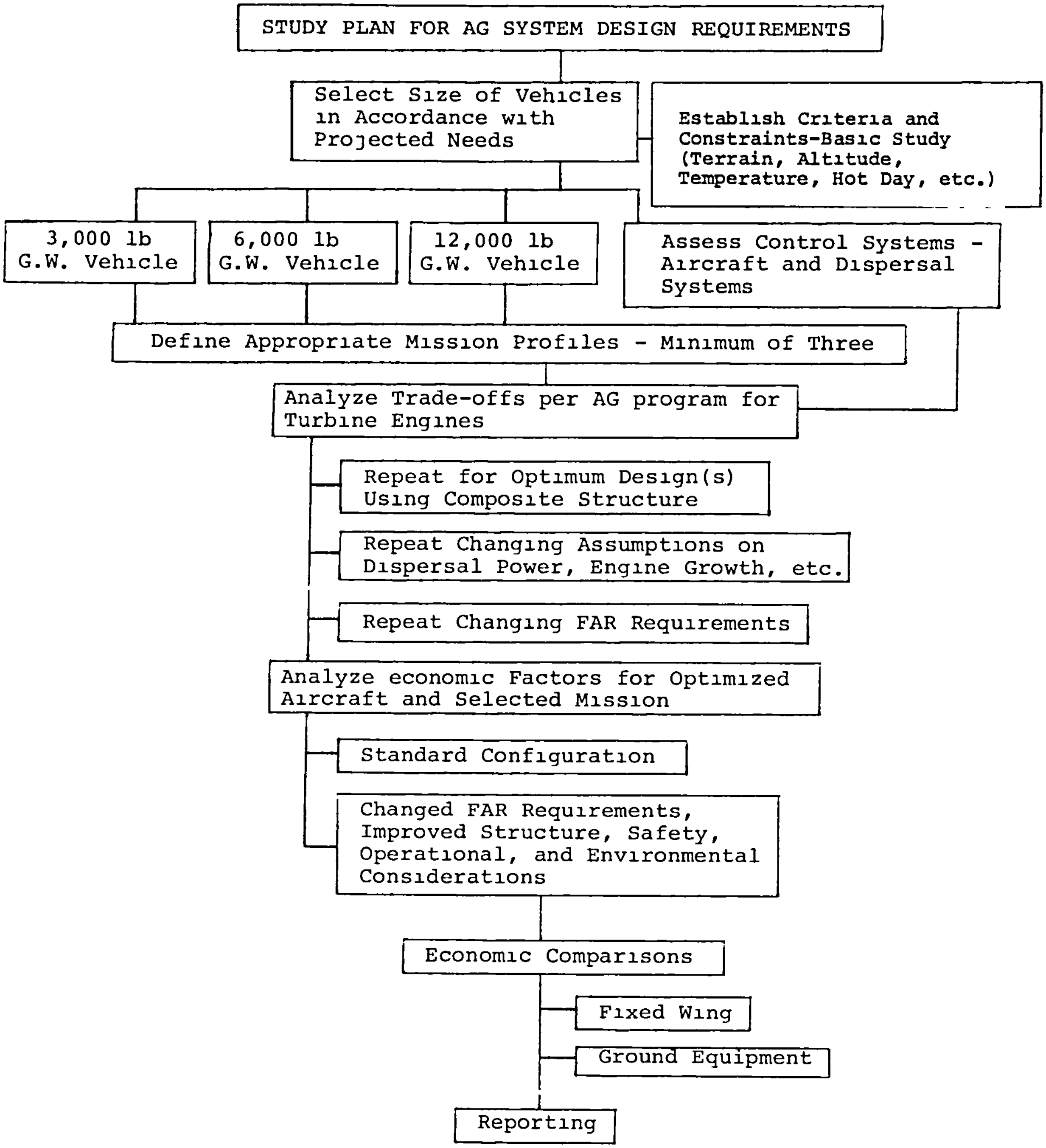

Figure 76. Study plan.

9. RESEARCH RECOMMENDATIONS

9.1 SELECTION CRITERIA

The research recommendations resulting from this study include:

1. Development and evaluation of various means of improving the effectiveness of the Ag applications system
2. Specific research for increasing the efficiency of general dispersal of liquids and solids
3. Specific research for improving safety of flight and for reducing exposure of personnel to chemicals
4. An examination of means for reducing costs
5. Specific research for improving the flying and operational qualities of the aircraft to reduce pilot burden

Research on the above should be concerned with basic fundamental principles as well as practical applications for the following reasons:

- With principles, in that new approaches (application of a known successful principle from another discipline) have often provided dramatic system improvements. Parametric relationships are most meaningful in efforts to optimize a helicopter or other system, i.e., tailoring a rotor system to dispersal use or designing a specific defect-tolerant structure.
- For practical applications, in that Ag dispersal technology has tended to be empirical in nature and, as such, is the result of the cut-and-try method. The application of scientific or engineering approaches to codify or improve a system often offers particular advantages in costs and better methodology for long range efforts.

Improvement in a system is often based on the upgrading of its components and the establishment of a more harmonious relationship in the exercise of its functions. In other cases, where complete system discard is required, a new design is often necessary depending upon the severity of the improvement requirements. Components of the Ag aerial dispersal system recommended to be examined are the aircraft, its airborne equipment, the material ground handling and servicing apparatus, and system operating methodology. Research is performed by studies, theoretical and practical analysis, tests (bench, model, full-scale, flight, ground, etc.) on various apparatus (wind tunnels, tow tunnels, free-flight and full-scale models, etc.), and experiments. Common to any research program is the need of an objective, a plan of approach, and a definition of the level of technology to which the program will attain. It may generally be stated that the lowest technology system which functions properly has the greatest probable chance for success, i.e., systems must be simple, maintenance free, reliable, precise, and safe with costing a prime consideration.

9.2 RESEARCH AREAS

Based on the results of this study, the review of the helicopter accident statistics, and the opinion survey of Ag operators and pilots, a list of recommended topics, objectives, and decision influences are presented as Table 14 of this section.

Figure 77 is a morphological chart showing programs implementing the investigation of some of the areas noted on Table 14.

TABLE 14. POTENTIAL AREAS FOR AG SYSTEM RESEARCH

A = Aircraft
AE = Aircraft Equipment
G = Ground Equipment

ITEM	CLASSIFI-CATION OF OBJECTIVE	HELICOPTER OPERATOR RATING	TREATED SYSTEM COMPONENT	REMARKS AND INFORMATION
1 Cockpit crash survivability a. High energy rotors b Energy absorbing structure c Gyroscope or other standby energy	3	1 0	A	1. Avoidance of problem a Eliminate deadmans curve - better autorotation qualities b Crashworthiness c More reliable engines 2. Better structure, i.e , concepts and corrosion resistance 3 Bendable booms
2. Drift control a. Nozzle improve-ment b Lifting boom c. Liquid controls d. On-off controls	1,2,3,4,5	90	AE,A	1. Droplet size control a. Inertia separator b. Tip curtain c Nucleating agents 2 Chemical controls 3 Swath control - width, streaking, coverage
3. Protection of pilot from toxic substances	3,5	82	A	1 Cabin pressurization with intake air filtering ECU developments - different approaches
4 Ground obstacle detection and avoidance	3,5	80	A	1. Operating techniques 2. Wire strike protected aircraft requirement a. Aircraft structure b. Rotors c Dispensing equipment
5. Improved erosion and corrosion resistance a. Materials b. Designs c Treatments d. Primary structures e Booms f. Nozzles g Blades	3,4,5	.62	A,AE,G	1. Specially formulated composites 2 Defect tolerant design 3. Coating protection development 4. Integral washdown systems
6 Establish desir-able standards for aircraft equipment and operations a. Sprayers b. Solids dis-pensing c Marking systems 1) Day 2) Night d Heads-up displays	1,2,3,4,5	-	A,AE,G	1 Effectivity of equipment unknown a. Coverage b. Penetration c. Streaking d Swath width effects e Vortex effects 2. Controls - specification factor evaluation
7 Aircraft improve-ments Lift capacity Performance Variable stability and controllability Engine relia-bility Reduced weight vehicle	1,2,3,5		A	1. Optimized Ag use rotor 2 Guarded T/R 3 Variable controls N O E. flight 4. Specific use vehicle studys, Ag prototypes
8 Ground equipment improvements Materials Designs Assisted T O helps			G	1. Composite tank, loaders, transfer equipment 2. Specific aircraft quality designs 3 T O & truck ground speed
9 Operational areas Superswaths Flight path potentials Night flight Patterns Assisted T O	1,4		A,G	1. Rotor dispersal 2. Lofted swaths 3. Night flight 4 Maze flight and drift control 5. Assisted T O a. Moving platform b. Boosted power c Stored energy sources
10 Electronic refinements Marking devices Heads-up display Night flight	5		G	1. Zyglo and black light 2 Electronic superposition of flight path 3 Viable display item evaluation and methodology

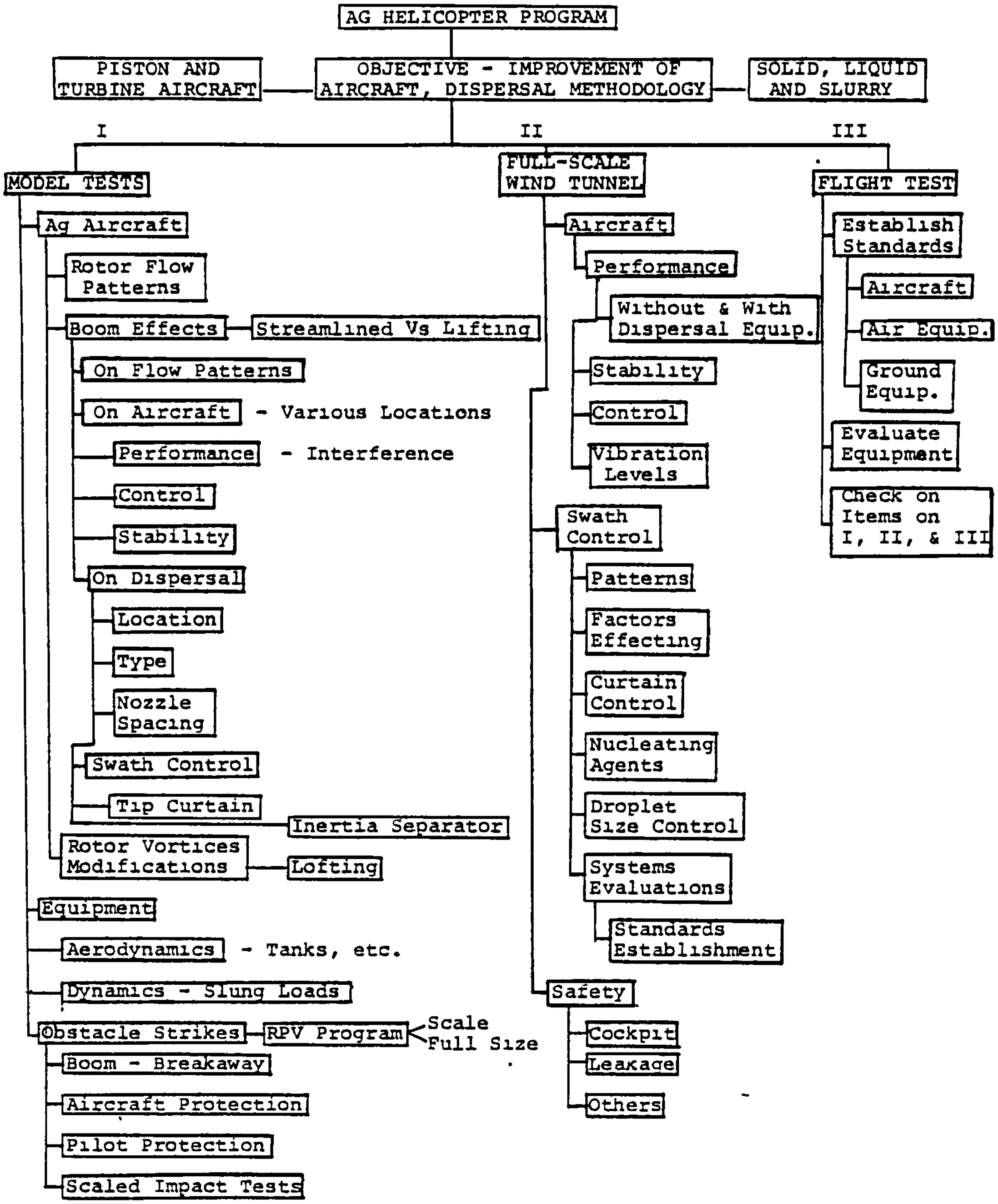

Figure 77. Implementing test programs.

10. RESULTS OF STUDY

The study of this report has resulted in the following.

10.1 STATE-OF-THE-ART SURVEY

The object of this survey is a definition of the state of the art of contemporary helicopter aerial dispersal of solids, liquids, and slurries. This includes a survey of present helicopter and airborne/ground equipment, and system needs.

10.2 LIMITATIONS

Establishment of restraints to Ag aerial dispersal by technical limitations to the state of the art are defined to indicate areas for potential improvements; mission definitions and possible future expansions are noted.

10.3 DESIGNS AND EVALUATIONS OF AIRCRAFT, EQUIPMENT, AND OPERATIONS

Typical designs for Ag use to evaluate present and future potentials were made for computer synthesis analysis. Selected modifications to these aircraft for design sensitivity effects were evolved and investigated by computer programs (swath effects and synthesized aircraft) based on improved equipment and operational techniques.

10.4 COST COMPARISONS

Basic comparison costs were studied as follows:

- Single Swath - State of the Art

  The basic effectiveness of the helicopter system using comparison rules was made to determine elemental (basic flight hour) costs.

- Mission Costing

  Day-to-day costs as might be encountered by three types of operations were analyzed by computer.

Typical Operations	A	- 25 Acres
	B	- 45 Acres
	C	- 200 Acres

10.5 EFFECTS OF CHANGES

Improvements in designs and swath widths for operations were factored into the computer studies to investigate the effects of various changes on the efficiency of the Ag operation. Specials showed improvements for costing and 1985 high technology appears obtainable at weights equivalent to those of current helicopters.

10.6 RESEARCH RECOMMENDATIONS

Research recommendations based on knowledge gained in the study, review of previous NASA work, and other sources resulted in the following desirable objectives and recommended areas of research:

- Objectives
    - Improving productivity, i.e., P.I.P.
    - Increasing dispersal efficiency of solids and liquids
    - Improving safety of flight by changing aircraft design features for less exposure to chemicals
    - Bettering of system flying and operational qualities to reduce pilot burden
    - Reductions in cost
- Recommended Research Areas
    - Cockpit crash survivability
    - Drift control
    - Pilot protection from toxic substances
    - Obstacle detection and avoidance
    - Improved corrosion resistance
    - Establish equipment standards

- Improvements
  - Aircraft
  - Ground equipment
  - Operational areas
- Electronic refinements

10.7 COST COMPARISON OF AIRPLANES, GROUND EQUIPMENT, AND HELICOPTERS

These were made based on fields of different sizes and varying aspect ratios. Helicopters are indicated as superior to both airplanes and ground equipment.

10.8 DETAILED INVESTIGATIONS OF DISPERSAL EQUIPMENT POWER REQUIREMENTS

These were evaluated to determine possible effects on mission performance of various methods of generating dispersal power. Results appear to indicate negligible power requirements of 2 to 3 percent of the main engine power.

11. CONCLUSIONS

Some of the general conclusions that may be drawn from this study investigation are the following:

- The state-of-the-art study of helicopter systems for the aerial dispersal of Ag materials indicates a viable, healthy, expanding business situation based on the following:

  - The use of obsolescent piston-powered helicopters, first introduced in 1947, which will continue to perform current missions.

  - The expansion of the application of turbine-powered helicopters to perform both the piston-powered missions as well as new applications.

- Current constraints to overall improved efficiencies of the helicopter, the aerial dispersal system, and the ground support system exist in the following forms:

  - Aircraft - Special purpose Ag vehicles (not subject to FAA general aviation requirements), although more effective than multipurpose helicopters, tend to be limited by costs, season length, and by the need for the many types of product dispersal required. Aircraft obsolescence tends to restrict improved productivity of the piston-powered fleet.

  - Aerial Dispersal Equipment - This reflects the cut-and-try nature of the business. Drift control is most important both from a safety standpoint and the percentage loss cost of the fines. The lack of rapid equipment adjustability to handle crop flexibility and dispersal rates for controllability of spray or solid materials prevents increasing practical productivity, i.e., changing nozzle adjustments and flow rates for coverage variations (swath width, penetration, elimination of streaking) on contemporary equipment tends to be time consuming and, therefore, expensive.

  - Row marking and helicopter weighing apparatus, when required, are costly to acquire but appear applicable to specific situations. Reduced cost equipment with equal capability would be most welcome.

- Ground Support Equipment - The advantages of a helipad tank truck support system located at the edge of a to-be-sprayed field are significant. This truck must be sized and equipped to handle the needed quantity of the dispersed materials and fuel, and be a source of equipment and aircraft substaining parts for one or more helicopters (often a mix of piston- and turbine-powered vehicles).

- Operational constraints exist in the consideration of the aircraft, government regulations (Federal, State, and local), and ambient effects (growing seasons, winds, darkness) as follows:

    - Aircraft using variable control and stability for accommodating wide gross weight changes for special Ag helicopters should be developed to improve flying qualities. Safety of flight should be achieved by using forgiving design features to minimize risk to the pilot.

    - Relaxation of operational regulations are expected to be possible for Ag specials, but general FAA requirements for helicopters are necessary where passengers are to be carried.

    - Night flight and heads-up displays may permit an expansion of treatments in that winds are low at night and improved flying may be achieved by better display techniques.

- A need exists for the establishment of standards for agricultural aircraft specials, dispersal equipment, and ground service vehicle systems. At the present time, the various special criteria qualities needed for evolving superior dispersal equipment are ill-defined and valid programmed test data are lacking. Qualification and characteristics determinations are required. BHT, with a Model 206 helicopter, has been performing such standards investigations on a limited scale in conjunction with the Simplex Manufacturing Company and the U.S. Department of Agriculture at the Agricultural Research Laboratory in Yakima, Washington. The "lofted swath" technique described herein is the result of such cooperation and serves as a practical example of the possible potential of standards establishment for equipment. Service characteristics of ground vehicles should be additionally evaluated in a similar manner as should marking systems.

- In order to improve the effectivity of Ag aerial dispersal of materials, the identified problems, techniques, and methodology noted herein should be researched, developed, and incorporated in Ag helicopter systems by a master organization (NASA or other) to provide a cooperative rallying point. The need for an organized overall program to guide the possible technical improvements available for Ag aerial dispersal systems is evident. The impact of the applications of current and future computer and other electronic technologies, as well as aerodynamic refinements, for example, has only been slight to data because of a lack of proven problem definition, indicated areas of need, and sufficient financial support. The scope of this effort lies beyond the capacity of individuals, corporate, or organizational (HAAA or HAA) entities in both technological and financial capabilities in that cross-discipline interrelationships are involved that tend to be unique to government agencies.

APPENDIX A

AIRCRAFT AND EQUIPMENT DATA TABLES

TABLE A-1. ROTARY WING AGRICULTURAL AIRCRAFT-PISTON POWERED UTILITY AND AG ONLY

Mfg & No. In Service	Model	Wt Empty kg(lb)	G Wt. kg(lb)	Chem Load kg(lb)	Capacities: Chemical lt (gal)	Capacities: Fuel lt (gal)	Cruise Speed km/hv (mph)	Range km(miles)	Service Ceiling m (ft)	Rate of Climb m/min (ft/min)	Power Hp @ RPM	Power Plant	Rotor Dia m(ft)	Max. Height m(ft)	Present Purchase Cost	[illegible]	Cost/Hr $ [illegible] Hr
[illegible] Aircraft																	
Bell	47G-3B-2	838(1848)	1338(2950)	337(740)	454(120)	227(60)	141(88)	418(260)	5610(18,400)	302(970)	280	Lyc TVO-435	11 32(37.2)	2 83(9.3)	55,000	.625	73.55
	47G-3B-1	845(1863)	1338(2950)	329(725)			128(80)		6400(21,000)		270	Lyc TVO-435	11.32(37 2)	2 83(9 3)	46,000	[illegible]	
500	47G-4A	838(1848)	1336(2950)	337(740)			136(85)	418(260)	3415(11,200)		280	Lyc VO-540	11.32(37 6)	2 83(9.3)	55,000	[illegible]	
	47G-5	771(1700)	1293(2850)	358(790)	454(120)	227(60)	135(84)	547(340)			265		11.32(37.2)	2.83(9.3)	48,000	.596	
Brantly-Hynes	B-2	454(1000)	757(1670)				129(80)	362(225)				Lyc 1VO-360-A1A	7.2(23 6)	2.07(6.8)	49,500	[illegible]	
9	305	771(1700)	1315(2900)				145(90)	442(275)				Lyc 1VO-540-B1A	8.69(28 5)	2.44(8.0)		55[illegible]	
Enstrom [illegible]	F28C	671(1480)	1179(2600)	345(760)			121(75)	398(247)				Lyc H1O-360-E1AD	9.75(32.0)	2.78(9.1)	69,000	.57	
Hiller	[illegible]	798(1759)	1225(3100)	272(600)	635(168)	174(46.0)	140(87)	298(185)	4756(15,500)		305	Lyc VO-540	10.80(35.4)	3.10(10.2)	45,000	.65	
[illegible]	[illegible]		1361(3000)				145(90)		5488(18,000)		320				65,000		
Hughes	300	435(958)	757(1670)	195(430)	304(80)	114(30)	97(60)	355(220)	3963(13,000)		180	Lyc H1O-360	7.70(25.3)	2.50(8.9)		[illegible]	
[illegible]	300C	476(1050)	975(2150)	372(820)	304(80)	114(30)	160(99)		4570(15,000)		190	Lyc H1O-360			76,945	.488	[illegible]
Sikorsky 14	H-19			1361(3000)	852(225)												
	S-58																
Ag Use Only																	
Continental Copters 15	El Tomcat [illegible] (Bell 47-G2)	562(1240)	1179(2600)	454(1000)		95(25)	141(88)	418(260)	5610(18,400)		235	Lyc VO-435	11.32(37.2)	2.83(9.3)	56,000	475	
Texas Hel Corp.	M74A	658(1450)	1225(2700)	290(641)	454(120)		129(80)	241(150)			265	Lyc VO-435 Derated			60,548	[illegible]	
12	M74	658(1450)	1111(2450)		454(120)		129(80)	241(150)			220	Lyc VO-435 Derated			55,6[illegible]0	[illegible]	

TABLE A-2. ROTARY WING AGRICULTURAL AIRCRAFT-TURBINE POWERED UTILITY AND AG ONLY

Mfg. & No. in Service	Model	Wt Empt/ kg(lb)	GW kg(lb)	Chem Load kg(lb)	Capacities: Chemical lt (gal)	Capacities: Fuel lt (gal)	Cruise Speed km/hr (mph)	Range km(miles)	Service Ceiling m (ft)	Rate of Climb m/min (ft/min)	Power kw (hp)	Power Plant	Rotor Dia m(ft)	Max Height m(ft)	Present Purchase Cost $	Wf WE GW	Cost hr $ [illegible] Hr
[illegible] Aircraft																	
Aerospatiale [illegible]	Lama	1024(2257)	2300(5070)	1136(2490)	1130(300)	174(46)	167(104)	515(320)	3292(10,800)	234(768)	404(542)	Turbomeca Artouste IIID	11.02(36.2)	3.9([illegible]0.14)	295,000	.444	
Bell [illegible]	Model 47 Soloy Conv											Allison 250-C20B					
	[illegible]	2249(49[illegible]8)	4763(10500)	2171(4793)		814(215)	167(104)	322(200)			1044(1400)	Lyc T53-13B	14 69(48 19)	3 9[illegible](12 [illegible])	[illegible]	[illegible]	3[illegible]
	[illegible]	767([illegible])	1633(3600)	685(1510)		288(76)	180(112)	322(200)			298(400)	Allison 250-C20	10 1(33 3)	2 7[illegible](9 05)	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible](1962)	1814(4000)	743(1638)			180(112)				313(420)	Allison 250-C20B	11.28(3[illegible] 0)	2.[illegible](9 [illegible])	295,[illegible]	.4[illegible]	
	[illegible]	2777(6[illegible]22)	5040(11200)	2122(4678)			185(115)	420(261)	4328(14,200)		1193(1600)	2 P&W PT6T	14.7(48 19)	3.92(1[illegible] [illegible])	9[illegible]5,[illegible]	.54[illegible]	454 [illegible]
	[illegible]	33[illegible](7[illegible]59)	7257(16000)	4299(9478)			149(94 6)				2185(2930)	Lyc T55-08D	15.24(50 0)		1265,[illegible]	.466	
	222	1[illegible]01(3970)	3266(7200)	1284(2830)			223(138 4)	684(425)			895(1200)	2 Lyc LTS-101	11.9(39 0)	3.38(11.1)	750,000	.553	
Hiller	[illegible]H-12E/E4	712(1570)	1406(3100)	1513(1130)	480(127)		154(96)	303(188)		520(1706)	298(400)	Allison 250-C20B Soloy Conv			186,000	.5[illegible]6	[illegible]42.19
[illegible]	FH-1100	6[illegible]2(1415)	1247(2750)	401(885)		261(58)	217(133)	644(400)	4878(16,000)	488(1600)	236(317)	Allison 250-C16	10.80(35 5)	2.8(9.2)	165,000	.5[illegible]5	
		68[illegible](1500)	1588(3500)	735(1620)													
Hughes [illegible]	500D	637(1404)	1610(3550)	792(1745)	867(229)		145(90)	531(330)		518(1700)	276(370)	Allison 250-C20B	8.1(26 5)	2.7(8.9)	218,985	.396	[illegible]
Sikorsky	S-58T	34[illegible]0(7671)	5986(13000)	2075(4374)		1070(283)	204(126 5)	448(278)	4570(15,000)	390(1280)	1250(1675)	2 P&W PT6T-6	17 07(56 0)	4 05(15.92)	5[illegible]0,003	.390	
Vertol	107	6093(13432)	9435(20800)				203(126)	383(238)				2 GE T58-10TS	15.5(51 0)	5 00(16.7)			
[illegible] Conversions																	
Continental Copters	Jet-Cut BHT 206 Conversion														Kit 20,000 Plus Aircraft		

TABLE A-3. AGRICULTURE HELICOPTER EQUIPMENT

[illegible] Dispersal [illegible]

I = Internal
E = External
S = Sling
EB = External Belly
ED = Engine Driven
EM = [illegible]
H = [illegible]
GD = [illegible]
C = Compressed [illegible]

[illegible]	[illegible]	[illegible] kg(lb)	Capacity Dry kg [illegible]	Capacity Liquid lt (gal)	Gross Weight Dry kg(lb)	Gross Weight Liquid lt (gal)	Location	Power Source	Power Reqd kw hp	Dispersal Rate-Max lt /min g/min	Boom Span m(ft)	Swath Width m(ft)	Aircraft Use	Initial Cost $	Vmax k/hr(mph)	Disposal rate, max [illegible]	Operative Speed [illegible]	Weight [illegible]	[illegible]
[illegible]	[illegible]	66 7 [illegible]		454(120)		502(1107)	E	ED			9 75(32)	14 6([illegible])	BHT 47	3850				[illegible]	[illegible]
[illegible]		77 1([illegible]70)		633(167)		683(1506)	I	ED		492 0(130)	15 2(50)	22 8(75)	Hughes 369H	10,000	193(120)			[illegible]	
	[illegible]	[illegible]	595(21)		686(1512)		S		7 83(10 5)				Any			998(2200)		[illegible]	[illegible]
[illegible]	[illegible]	[illegible] 248)		681(180)*		566(1248)	EB	EM			12 5(49)	22 4(73 5)	BHT 206		177(110)			[illegible]	[illegible]
		[illegible]		681(180)		543(1197)	EB	EM			12 5(49)	22 4(73 5)	Hughes 500D		177(110)			[illegible]	[illegible]
	[illegible]	[illegible]		1136(300)		1221(2692)	EB	EM			13 0(50)	22 8(75 0)	Lama		225(140)		[illegible]	[illegible]	[illegible]
		[illegible]		416(1[illegible]0)		440(971)	E	H			12 2(40)	18 25(60)	Hiller 12E					[illegible]	[illegible]
	[illegible]	[illegible]		454(120)		461(1016)	E	ED			15 0(49)	22 4(73 5)	BHT 47					[illegible]	[illegible]
		[illegible]		416(1[illegible]0)		448(987)	E	ED		302 0(80)	12 2(40)	18 25(60)	Hiller 12E					[illegible]	
		[illegible]		416(110)		448(987)	E	ED		302 0(80)	12 2(40)	18 25(60)	Hiller 12E					[illegible]	
		[illegible]		416(110)		448(987)	E	ED		302 0(80)	12 2(40)	18 25(60)	BHT 47					[illegible]	
	[illegible]	[illegible]		[illegible](140)		608(1340)	E	ED		568 0(150)	16 0(53)	24 2(79 5)	Hiller 12E					[illegible]	
	[illegible]	[illegible]		5[illegible]0(140)		608(1340)	E	ED		568 0(150)	16 0(53)	24 2(79 5)	BHT 47					[illegible]	[illegible]
	[illegible]	[illegible]	396[illegible] 40[illegible]		570(12[illegible]6)		E						Any				[illegible]	[illegible]	
	[illegible] water	[illegible]	3964 [illegible]0)		596(1314)		E	ED,CD •					NA				[illegible]	[illegible]	
	[illegible] water	[illegible]	3[illegible]64(140)		596(1314)		E	ED,CD					Bell 47				2.5 [illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	567 [illegible]		658(1450)		S	GD	7 457(10)			45 6(150)	Hiller 12E			[illegible] 300)	[illegible]	[illegible]	
	[illegible]	[illegible]	[illegible]13[illegible](45)		1240(2735)		S	GD	7 457(10)			45 6(150)	NA			1088(2400)		[illegible]	
		37[illegible]	2[illegible]66(80)		2642(5825)		S	GD	59 66(80)			60 8(200)	NA			1088([illegible]400)		[illegible]	[illegible]
	[illegible]	42 [illegible]	567(20)		649(1430)		S	ED		9085 0(2400)		37 0(120)	NA					[illegible]	[illegible]
	[illegible]	134 0(2[illegible])		585(150)		678(1495)	S	GD	5 966(8)	379 0(100)	12 2(40)	18 25(60)	NA			2[illegible]22(6000)		[illegible]	[illegible]
	[illegible]	14[illegible]		11[illegible](300)		1233(2720)	S	ED	5 966(8)	379 0(100)	12 2(40)	18 25(60)	NA					[illegible]	[illegible]
[illegible]	[illegible]	42 7(94)		340 5(90)	369(814)		I	C			10 7(35)	15 97(52 5)	Hughes 269	3995				[illegible]	[illegible]
	[illegible]			37 8(10)		54(120)	I	C											
[illegible]	[illegible]			522(138)			E	ED		787 0(208)			BHT 47G						
	[illegible] water			454(120)			E	ED, H					Hiller 12E						[illegible]
	[illegible]	5[illegible]		567 5(150)		612(1350)	S	GD	5 22(7)		14 02(46)	21.83(69)						[illegible]	[illegible]
		33 8 [illegible]95)		832(220)		660(1955)	S	GD	5 22(7)										
	[illegible]	[illegible]3[illegible] 6(288)	56700(2000)		1038(2288)		S	CD	5 22(7)							1133([illegible]500)		[illegible]	[illegible]
	[illegible]	1[illegible]6 0(256)	42525(1500)		797(1756)		S	GD	5 22(7)							1133(2500)		[illegible]	[illegible]
	[illegible]						S	GD	5 22(7)							1133([illegible]400)		[illegible]	
	[illegible]						S	ED, H								6[illegible](1800)			

*Capacity [illegible] gallons does not equate to stated brochure weights

TABLE A-4. ROTARY WING PISTON POWERED AGRICULTURE AIRCRAFT AND EQUIPMENT

Aircraft	GW kg(lb)	Equipment	Eq Wt Empty kg(lb)	Eq GW kg(lb)	Aircraft load kg(lb)
BHT 47G	1338(2950)	AG King 500B	66.7(147)	502(1107)	337(742)
		Simplex 486	100.0(220)	608(1340)	
		Simplex 597	85.0(187)	448(987)	
		Simplex 1620 Seeder	61.7(136)	570(1256)	
		Simplex 4400 Duster	88.0(194)	596(1314)	
		Simplex 3720 Spreader Bucket	90.7(200)	658(1450)	
		Simplex 2000 Liq Bucket	134 0(295)	678(1495)	
		Simplex 1900 Liq Spray Bk	82.0(180)	649(1430)	
		Sorensen ULV		54.4(120)	
		Transland Spray King	68.0(150)	612(1350)	
		Transland Sling King 1000	102.0(225)	556(1225)	
BHT 47A	1293(2850)	Ag King 500B	66.7(147)	502(1107)	358(790)
		Simplex 486	100.0(220)	608(1340)	
		Simplex 597	85.0(187)	448(987)	
		Simplex 1620 Seeder	61.7(136)	570(1256)	
		Simplex 4400 Duster	88.0(194)	596(1314)	
		Simplex 3720 Spreader Bucket	90.7(200)	658(1450)	
		Simplex 2000 Liq Bucket	134.0(295)	678(1495)	
		Simplex 1900 Liq Bucket	82.0(180)	649(1430)	
		Sorensen ULV		54.4(120)	
		Transland Spray King	68.0(150)	612(1350)	
		Transland Sling King 1000	102.0(225)	556(1225)	
Enstrom F28C		Chadwick C499	95.3(210)	686(1512)	345(760)
		Simplex 3720 Spreader Bucket	90.7(200)	658(1450)	
		Simplex 2000 Liq Bucket	134.0(295)	678(1495)	
		Simplex 1900 Liq Bucket	82.0(180)	649(1430)	
		Sorensen ULV		54.4(120)	
		Transland Spray King	68.0(150)	612(1350)	
		Transland Sling King 1000	102.0(225)	537(1225)	

TABLE A-4. ROTARY WING PISTON POWERED AGRICULTURE AIRCRAFT AND EQUIPMENT (Concluded)

Aircraft	GW kg(lb)	Equipment	Eq Wt Empty kg(lb)	Eq GW kg(lb)	Aircraft load kg(lb)
Hiller UH-12E.	1225(2700)	Simplex 3300	78.0(171)	440(971)	272(600)
		Simplex 550	85.0(187)	448(987)	272(600)
		Sorensen ULV		54.4(120)	272(600)
UH-SL4	1361(3000)	AG King 500B	66.7(147)	502(1107)	408(900)
		Chadwick C499	95.3(210)	686(1512)	
		Simplex 1300	80.0(176)	461(1016)	
		Simplex 550	85.0(187)	448(987)	
		Simplex 570	85.0(187)	448(987)	
		Simplex 765	100.0(220)	608(1340)	
		Simplex 1620 Seeder	61.7(136)	570(1256)	
		Simplex 3720 Spreader Bucket	90.7(200)	658(1450)	
		Simplex 1900 Liq Bucket	82.0(180)	649(1430)	
		Simplex 2000 Liq Bucket	137.0(295)	678(1495)	
		Sorensen ULV		54.4(120)	
		Transland Spray King	68.0(150)	612(1350)	
		Transland Sling King 1000	102.0(225)	556(1225)	
Hughes 300	757(1670)	Sorensen ULV		54.4(120)	195(530)
300C	975(2150)	Sorensen ULV		54.4(120)	372(820)
Continental Tomcat	1179(2600)	AG King 500	66.7(147)	502(1107)	494(1090)
		Simplex 3720 Spreader Bucket	90.7(200)	658(1450)	
		Simplex 2000 Liq Bucket	134.0(295)	678(1495)	
		Sorensen ULV		54.4(120)	
		Transland Spray King	68.0(150)	612(1350)	
		Transland Sling King 1000		567(1250)	
Texas Hel M74	1111(2450)	AG King 500	66.7(147)	502(1107)	290(640)
		Sorensen ULV		54.4(120)	290(640)

TABLE A-5. ROTARY WING TURBINE POWERED AIRCRAFT AND EQUIPMENT

Aircraft	GW kg(lb)	Equipment	Eq Wt Empty kg(lb)	Eq GW kg(lb)	Aircraft load kg(lb)
Aerospatiale Lama	2300(5070)	Simplex 3400	132.0(292)	1221(2692)	1130(2493)
		Simplex 1620 Seeder	61.7(136)	570(1256)	
		Simplex 3740 Spreader Bk	107.0(235)	1240(2735)	
		Simplex 2200 Liq Sp Bucket	145.0(320)	1233(2720)	
		Transland Spray King	133.8(295)	660(1955)	
		Transland Sling King 2000	130.6(288)	1038(2288)	
		Transland Sling King 1500	116.0(256)	797(1756)	
BHT 205A-1	4763(10500)	Chadwick C499	95.3(210)	686(1512)	2174(4793)
		Simplex 597	85.0(187)	448(987)	
		Simplex 486	100.0(220)	608(1340)	
		Simplex 1620 Seeder	61.7(136)	570(1256)	
		Simplex 3740 Spreader Bk	107.0(235)	1240(2735)	
		Simplex 2200 Liq Sp Bucket	145.0(320)	1233(2720)	
		Transland Spray King	133.8(295)	660(1455)	
		Transland Sling King 2000	130.6(288)	1038(2288)	
		Transland Sling King 1500	116.0(256)	797(1756)	
206B	1633(3600)	Simplex 2700	113.0(248)	566(1248)	685(1510)
		Simplex 597	85.0(187)	448(987)	
		Simplex 1620 Seeder	61.7(136)	570(1256)	
		Simplex 3720 Spreader Bk	90.7(200)	658(1450)	
		Simplex 1900 Liq Sp Bucket	82.0(180)	649(1430)	
		Sorensen ULV		54.4(120)	
		Transland Spray King	68.0(150)	612(1350)	
		Transland Sling King 1000		556(1225)	
206L	1814(4000)	Simplex 2700	113.0(248)	566(1248)	743(1638)
		Simplex 597	85.0(187)	448(987)	
		Simplex 1620 Seeder	61.7(136)	570(1256)	
		Simplex 3720 Spreader Bk	90.7(200)	568(1450)	
		Simplex 1900 Liq Sp Bucket	82.0(180)	649(1430)	
		Sorensen ULV		54.4(120)	
		Transland Spray King	68.0(150)	612(1350)	
		Transland Sling King 1000		556(225)	

TABLE A-5. ROTARY WING TURBINE POWERED AIRCRAFT AND EQUIPMENT (Continued)

Aircraft	GW kg(lb)	Equipment	Eq Wt Empty kg(lb)	Eq GW kg(lb)	Aircraft load kg(lb)
BHT 212	5080(11200)	Chadwick C499	95.3(210)	686(1512)	2122(4678)
		Simplex 597	85.0(187)	448(987)	
		Simplex 486	100.0(220)	608(1340)	
		Simplex 1620 Seeder	61.7(136)	570(1256)	
		Simplex 2200 Liq Sp Bk	145.0(320)	1233(2720)	
		Transland Spray King	133.8(295)	660(1455)	
		Transland Sling King 2000	130.6(288)	1038(2288)	
		Transland Sling King 1500	116.0(256)	797(1756)	
214	7257(16000)	Chadwick C499	95.3(210)	686(1512)	4299(9478)
		Simplex 597	85.0(187)	448(987)	
		Simplex 1620 Seeder	61.7(136)	570(1256)	
		Simplex 3740 Spreader Bk	107.0(235)	1240(2735)	
		Simplex 3500 Spreader Bk	375.0(825)	2642(5825)	
		Simplex 1900 Liq Sp Bk	82.0(180)	649(1430)	
		Simplex 2000 Liq Sp Bk	134.0(295)	678(1495)	
		Simplex 2200 Liq Sp Bk	145.0(320)	1233(2720)	
		Sorensen ULV		54.4(120)	
		Transland Spray King	133.8(295)	660(1955)	
		Transland Sling King 1000			
		Transland Sling King 1500	116.0(256)	797(1756)	
		Transland Sling King 2000	130.6(288)	1038(2288)	
222	3266(7200)	Chadwick C499	95.3(210)	686(1512)	1284(2830)
		Simplex 597	85.0(187)	448(987)	
		Simplex 1620 Seeder	61.7(136)	570(1256)	
		Simplex 3740 Sprader Bk	107.0(235)	1240(2735)	
		Simplex 1900 Liq Sp Bk	82.0(180)	649(1430)	
		Simplex 2000 Liq Sp Bk	134.0(295)	678(1495)	
		Simplex 2200 Liq Sp Bk	145.0(320)	1233(2720)	
		Sorensen ULV		54.4(120)	
		Transland Spray King	133.8(295)	660(1955)	
		Transland Sling King 1000			
		Transland Sling King 1500	116.0(256)	797(1756)	
		Transland Sling King 2000	130.6(288)	1038(2288)	

TABLE A-5. ROTARY WING TURBINE POWERED AIRCRAFT AND EQUIPMENT (Concluded)

Aircraft	GW kg(lb)	Equipment	Eq Wt Empty kg(lb)	Eq GW kg(lb)	Aircraft load kg(lb)
Hiller UH-12E	1406(3100)	Chadwick C499	95.3(210)	686(1512)	513(1130)
		Simplex 3300	78.0(171)	440(971)	
		Simplex 1300	80.0(176)	461(1016)	
		Simplex 550	85.0(187)	448(987)	
		Simplex 765	100.0(220)	608(1340)	
		Simplex 1620 Seeder	61.7(136)	570(1256)	
		Simplex 3720 Spread Bk	90.7(200)	658(1450)	
		Simplex 1900 Liq Sp Bk	82.0(180)	649(1430)	
		Simplex 2000 Liq Sp Bk	134.0(245)	678(1495)	
		Sorensen ULV		54 4(120)•	
		Transland Spray King	68.0(150)	612(1350)	
		Transland Sling King 1000		567(1250)	
FH-1100	1247(2750)	Simplex 1300	80.0(176)	461(1016)	401(885)
		Simplex 550	85.0(187)	448(987)	
		Simplex 765	100.0(220)	608(1340)	
		Sorensen ULV		54.4(120)	
		Transland Spray King	68.0(150)	612(1350)	
		Transland Sling King 1000		567(1250)	
Hughes 500D	1610(3550)	Chadwick C500	771.0(170)	683(1506)	792(1745)
		Simplex 5000	90.0(197)	543(1197)	
		Simplex 3720 Spreader Bk	90.7(200)	658(1450)	
		Simplex 1900 Liq Sp Bk	82.0(180)	649(1430)	
		Simplex 2000 Liq Sp Bk	134.0(295)	678(1495)	
		Sorensen ULV		54.4(120)	
		Transland Spray King	133.8(295)	660(1955)	
		Transland Sling King 1500	116.0(256)	797(1756)	
Sikorsky S-58T	5986(13000)	Chadwick C499	95.3(210)	686(1512)	2075(4374)
		Simplex 3740 Bucket	107.0(235)	1240(2735)	
		Simplex 2000 Liq Sp Bk	134.0(295)	678(1495)	
		Simplex 2200 Liq Sp Bk	145.0(320)	1233(2720)	
		Sorensen ULV		54.4(120)	
		Transland Spray King	133.8(295)	660(1455)	
		Transland Sling King 2000	130.6(288)	1038(2288)	

P = Productivity = [illegible]

P.I. = Productivity Index = Productivity / Op cost [illegible]

P I P = PI x Width of Swath

TABLE A-6. PISTON POWERED HELICOPTERS

[illegible] of Productivity - Velocities, Payloads

Aircraft	V cruise I & II km/hr (mph)	Condition	V working Factor	V working	Max Payload kg (lb)	Equipment Used	Gross Wt kg (lb)	P	$/hr/600 hr	PI	Swath Width	P.I P	V working = [illegible] P	PI	[illegible]	[illegible]	[illegible]
B[illegible] 47 [illegible] 5	135(84)	3S	85	115(71 4)	272(600)	Simplex 597	1293(2850)	15.03	73 55	.204	24.2(79.5)	16 218	12.78	[illegible]	[illegible]	.593	[illegible]
		4S	80	108(67 20)	277(610)	Simplex 1900	1293(2850)	14.38	73 55	.196	24.2(79 5)	15 58	11 50	[illegible]	[illegible]	[illegible]	[illegible]
		3H	90	122(75 7)	272(600)	Simplex 4100	1293(2850)	15.94	73 55	217	24 2(79.5)	17 25	[illegible]	[illegible]	[illegible]	.531	[illegible]
		4H	85	115(71 4)	252(555)	Simplex 3740	1293(2850)	13.09	73 55	.178	24 2(79.5)	14.15	11 13	.151	12 [illegible]	[illegible]	[illegible]
Brantly B-2	135(80)	2S	90	116(72 0)		DNA	757 5(1670)	8.62	-	-	-						
		3S	85	109(68 0)	-												
		4S	80	103(64 0)	-												
		4H	85	109(68 0)	-												
Enstrom F28C	121(75)	3S	85	103(63 75)	277(610)	Transland Spray King	1179(2600)	14.96	-	-	12.2(40 0)	-	12 72	-	-		
		4S	80	97(60 0)	211(465)	Simplex 2000	1179(2600)	10.73			12 2(40 0)		8 58				
		3H	90	109(67 5)	254(560)	Simplex 3720	1179(2600)	14.54			12.2(40.0)		13 0[illegible]				
		4H	85	103(63 75)	240(530)	Chadwick 499	1179(2600)	13.00			12 2(40 0)		11 0[illegible]				
Hiller UH-12E	140(87)	3S	85	119(73 95)	186(410)	Simplex 550, 570	1225(2700)	11.23	75 00	.150	18.3(60 0)	9.00	9.55	[illegible]	7 [illegible]	[illegible]	[illegible]
		4S	80	112(69 6)	195(430)	Simplex 3300	1225(2700)	11.08	75.00	.148	18.3(60.0)	8.88	8 86	118	7.[illegible]	[illegible]	[illegible]
		3H	90	126(78 3)	-												
		4H	85	119(23 95)	-												
Hughes 300C	159(99)	3S	85	135(84 15)	-											.845	[illegible]
		4S	80	128(79 80)	-												
		3H	90	143(89.0)	-												
		4H	85	135(84 15)	-												
[illegible] Copters [illegible]	142(88)	3S	85	120(74 80)	428(943)	AG King 500B	1179(2600)	27.13	75 00	.362	24.2(79 5)	28 76	23 06	308	24 45	[illegible]	[illegible]
		4S	80	113(70 40)	361(795)	Simplex 2000	1179(2600)	21.53	75 00	.287	24.2(79 5)	22.82	17.22	230	18 [illegible]	[illegible]	[illegible]
		3H	.90	127(29 20)	404(890)	Simplex 3720	1179(2600)	27.11	75.00	.361	24.2(79.5)	28.74	24.40	[illegible]	[illegible] 90	[illegible]	[illegible]
		4H	85	120(74 80)	431(950)	Transland Sling King 1000	1179(2600)	27.33	75 00	.364	24 2(79 5)	28.97	23.23	.309	[illegible] 62	.335	[illegible]
Tex [illegible] Corp M74A	129(80)	3S	.85	109(68.0)	224(493)	AG King 300	1225(2700)	22.42	75 00	.166	24 2(79 5)	13 16	10.56	141	11 19	[illegible]	[illegible]
		4S	.80	103(64 0)	-												
		3H	90	116(72.0)	-												
		4H	85	109(68.0)	-												

DNA = Data Not Available

TABLE A-7. TURBINE POWERED HELICOPTERS

[illegible]

P = [illegible]

PI = P cost [illegible]

PIP = P I x Swath [illegible]

Aircraft	[illegible] (mph)	Condition	$V_{working}$ Factor	$V_{working}$ Km/hr (mph)	Max Payload Kg(lb)	Equipment Used	Gross Wt Kg(lb)	P	$/hr	PI	Swath Width m(ft)	P I P.	$/Acre	[illegible] P	PI	PIP	[illegible]
[illegible]	[illegible]67 104)	3S	85	142(88 4)	998(2200)	Simplex 3400	2300(5070)	38 36	373	103	22 9(75)	7 71	1.07	32 [illegible]	[illegible]	[illegible] 55	[illegible]
		4S	80	134(83 2)	987(2175)	Simplex 2200	2300(5070)	35 69	373	096	22 9(75)	7 18	1 14	28 55	[illegible]	[illegible]	[illegible]
		3H	90	151(93 6)	570(1256)	Simplex 1620	2300(5070)	20 61	373	055	22.9(75)	4 13	1 [illegible]	18 55	[illegible]	[illegible]	[illegible]
		4H	85	142(88 4)	1024(2258)	Simplex 3740	2300(5070)	39.37	373	106	22 9(75)	7.92	1 0[illegible]	33 [illegible]	[illegible]	[illegible]	[illegible]
[illegible]	167([illegible]04)	2S	90	151(93 6)			4763(10500)	33 87	373	091	61 0(200)	18 2	[illegible]53	[illegible]	[illegible]	[illegible]	[illegible]
		3S	85	142(88 4)	608(1340)	Simplex 4[illegible]6	4763(10500)	11 28	373	030	61 0(200)	[illegible] 05	1 3[illegible]	9 [illegible]	[illegible]	[illegible]	[illegible]
		4S	80	134(83 2)	1234(2720)	Simplex 2200	4763(10500)	21 55	373	058	61 0(200)	11 5[illegible]	714	[illegible]	[illegible]	[illegible]	[illegible]
		3H	90	151(93 6)	608(1340)	Simplex 486	4763(10500)	11 95	373	0320	61 0(200)	[illegible] 40	1 [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		4H	85	142(88 4)	1241(2735)	Simplex 3740	4763(10500)	23 03	373	0617	61 0(200)	12 35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible](112)	2S	90	161(100 0)	566(1248)	Simplex 2700	1633(3600)	39 37	122	323	22 4(73 5)	23 74	[illegible]48	[illegible] 43	[illegible]	[illegible]	[illegible]
		3S	85	153(95 2)	448(987)	Simplex 597	1633(3600)	26 10	122	213	22 4(73 5)	15 72	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		4S	80	144(89 6)	180(1330)	Simplex 1900	1633(3600)	33 10	122	271	22 4(73 5)	19 94	41[illegible]	[illegible] 48	[illegible]	[illegible]	[illegible]
		3H	90	162(100 8)	570(1256)	Simplex 1620	1633(3600)	35 17	122	288	22 4(73 5)	21 2	38[illegible]	31 [illegible]	[illegible]	[illegible]	[illegible]
		4H	85	153(95 2)	594(1310)	Simplex 3720	1633(3600)	34 64	122	284	22.4(73 5)	20 87	.395	[illegible] 4	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	2S	90	163(100 0)	566(1248)	Simplex 2700	1814(4000)	38 66	122	316	22 4(73 [illegible])	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		3S	85	153(95 2)	448(987)	Simplex 597	1814(4000)	23 49	122	193	22 4(73 5)	14 15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		4S	80	144(89 6)	662(1460)	Simplex 1900	1814(4000)	32 70	122	2[illegible]8	22 4(73 5)	19 7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		3H	.90	162(100 8)	570(1256)	Simplex 1620	1814(4000)	31 65	122	259	22.4(73 5)	19 07	.433	[illegible]	[illegible]	[illegible]	[illegible]
		4H	85	153(95 2)	658(1440)	Simplex 3720	1814(4000)	39 27	122	281	22.4(73 5)	20 65	400	[illegible]	[illegible]	[illegible].53	[illegible]
[illegible]	1[illegible]5(115)	2S	90	167(100 0)			5080(11200)	35 12	454	077	61 0(200)	14 4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		3S	85	157(97 8)	608(1340)	Simplex 486	5080(11200)	11 70	454	026	61 0(200)	5 15	1.[illegible]	[illegible]	[illegible]	4 [illegible]	[illegible]
		4S	80	148(92 0)	1233(2720)	Simplex 2200	5080(11200)	22 34	454	049	61 0(200)	9 84	838	[illegible]	[illegible]	7 [illegible]	[illegible]
		3H	90	167(103 5)	570(1256)	Simplex 1620	5080(11200)	11 61	454	0256	61 0(200)	5 113	1 [illegible]	10 45	[illegible]	4 [illegible]	[illegible]
		4H	85	157(97 8)	1038(2288)	Transland Sling King 2000	5080(11200)	19 98	454	.0440	61 0(200)	8 80	930	[illegible] 98	[illegible]	7.48	[illegible]
[illegible]	152(94 6)	2S	90	137(85 1)			7257(16000)	42 57	616	069	61 0(200)	13 8	[illegible]	30 [illegible]	[illegible]	9.8	[illegible]
		3S	85	129(80 4)	448(987)	Simplex 597	7257(16000)	4 96	616	0081	61 0(200)	1 [illegible]	5 12	[illegible]	[illegible]	[illegible]	[illegible]
		4S	80	121(75 7)	1233(2720)	Simplex 2200	7257(16000)	12 87	616	0209	61 0(200)	4 18	1 97	16 [illegible]	[illegible]	[illegible]	[illegible]
		3H	90	137(85 1)	570(1256)	Simplex 1620	7257(16000)	6 68	616	0108	61 0(200)	2 17	3 80	6 [illegible]	[illegible]	[illegible]	[illegible]
		4H	85	129(80 4)	2642(5825)	Simplex 3500	7257(16000)	29 27	616	0475	61 0(200)	9.503	[illegible]	24 88	[illegible]	[illegible]	[illegible]

TABLE A-7. TURBINE POWERED HELICOPTERS (Concluded)

[illegible]

Aircraft	Cruise km/hr (mph)	Condition	V working Factor	V working km/hr (mph)	Max Payload kg(lb)	Equipment Used	Gross Wt kg(lb)	P	$/hr	PI	Swath Width m(ft)	PIP	$ Acre Cruise	V working [illegible] P	PI	PIP	$ Acre
222	222 7(138 4)	3S	85	161(100 0)	448(987)	Simplex 597	3266(7200)	13 71	142 9	.0959	61.0(200)	19.19	.430	11 65	.0815	16.3[illegible]	.536
		4S	80	161(100 0)	1139(2510)	Simplex 2200	3266(7200)	34 86	142 19	245	61 0(200)	49 03	168	27 89	.196	39 22	[illegible]
		3H	90	201(124 0)	570(1256)	Simplex 1620	3266(7200)	21.8	142.19	153	61 0(200)	30 67	.269	19.62	138	27.63	[illegible]
		4H	85	190(118 0)	1134(2500)	Simplex 3740	3266(7200)	40 9	142 19	.288	61 0(200)	57 63	.143	34 77	.245	43.99	[illegible]
[illegible]																	
	154(96)	[illegible]	85	131(81 6)	433(954)	Simplex 1300	1406(3100)	25 11	142 19	176	18.3(60)	10 60	[illegible]	[illegible] 34	.150	[illegible]	[illegible]
		4S	80	124(76 8)	445(980)	Transland Spray King	1406(3100)	24.28	142 19	.171	18 3(60)	10 24	1 02	19 42	137	8 19	.226
		3H	90	139(86 4)	450(994)	Simplex 1620	1406(3100)	27 7	142 19	195	18 3(60)	11 70	[illegible]	[illegible]	[illegible]	10.53	[illegible]
		4H	85	131(81 6)	449(990)	Transland Sling King	1406(3100)	26.06	142.19	183	18 3(60)	10 99	.750	22.15	.155	9.34	.833
[illegible]	170(106)																
		3S	85	145(90 1)	322(709)	Simplex 1300	1588(3500)	18 25	142.19	.128	22.4(73 5)	9 43	.875	15.5	.109	8 [illegible]	1 03
		4S	80	136(84 8)	333(735)	Transland Spray King	1588(3500)	17.7	142.19	125	22 4(73 5)	9.16	.901	14 16	.100	7.33	1.23
		3H	90	154(95.4)			1588(3500)		142.19		22.4(73.5)						
		4H	85	145(90 1)	337(745)	Transland Sling King	1588(3500)	19 18	142 19	.134	22 4(73 5)	9 91	832	16 3	.114	8.42	[illegible]
[illegible]	225(140)	2S	85	161(100 0)			1610(3550)	61.54	136.00	453	22 4(73 5)	33 29	.453	31.02	.228	16 76	[illegible]
		3S	85	161(100 0)	543(1197)	Simplex 5000	1610(3550)	33 71	136 00	.248	22.4(73 5)	16 22	.453	28 65	[illegible]	15 48	[illegible]
		4S	80	161(100 0)	710(1565)	Simplex 1900	1610(3550)	44 08	136 00	.324	22 4(73 5)	23 8	.347	35 26	.259	19.04	[illegible]
		2H	95	214(133 0)	683(1506)	Chadwick 500	1610(3550)	56 4	136.00	415	22 4(73.5)	30 5	270	53 58	.394	28 96	[illegible]
		3H	90	203(126 0)	543(1197)	Simplex 5000	1610(3550)	42.49	136.00	.312	22 4(73 5)	22.96	.360	38.24	.281	20.61	[illegible]
		4H	85	192(119 0)	658(1450)	Simplex 3720	1610(3550)	48.60	136.00	357	22 4(73.5)	26.27	.314	41.31	.303	22.27	[illegible]
Sikorsky [illegible]	204(126.5)	2S	95	161(100 0)			5897(13000)	44 37			18 3(60)			22.15	-	-	
		3S	85	161(100 0)			5897(13000)				18 3(60)						
		4S	80	161(100 0)	1233(2700)	Simplex 2200	5897(13000)	20 77			18 3(60)			16.67			
		2H	95	193(120 0)			5897(13000)				18 3(60)						
		3H	90	183(114 0)			5897(13000)				18.3(60)						
		4H	85	174(108 0)	1240(2735)	Simplex 3740	5897(13000)	22.72			18.3(60)			19.31			
[illegible]ertol Model 107	203(126 0)	2S	.95	161(100 0)			9435(20800)	34.52						17.33	-	-	
		3S	85	161(100 0)			9435(20800)										
		4S	80	161(100 0)			9435(20800)										
		2H	.95	193(120 0)			9435(20800)										
		3H	.90	182(113 0)			9435(20800)										
		4H	.85	172(107 0)			9435(20800)										

APPENDIX B

PRODUCTIVITY CURVES

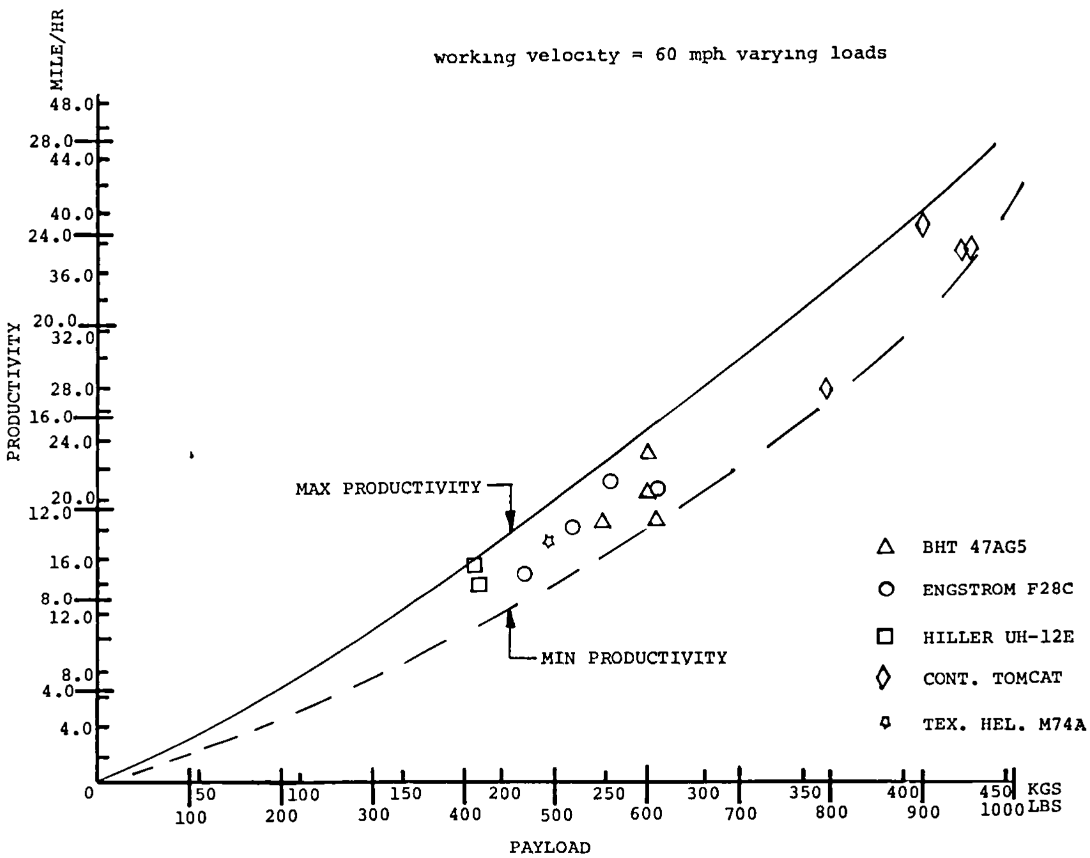

Figure B-1. Productivity vs payload.

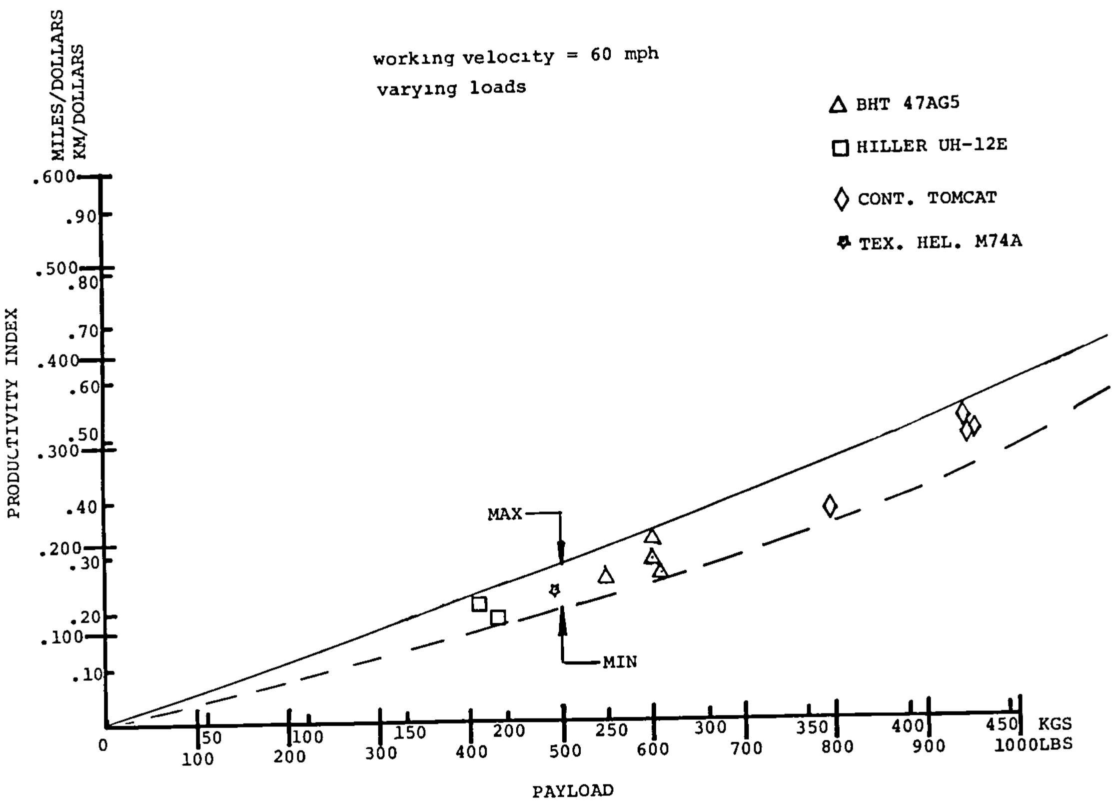

Figure B-2. Productivity vs payload, specials.

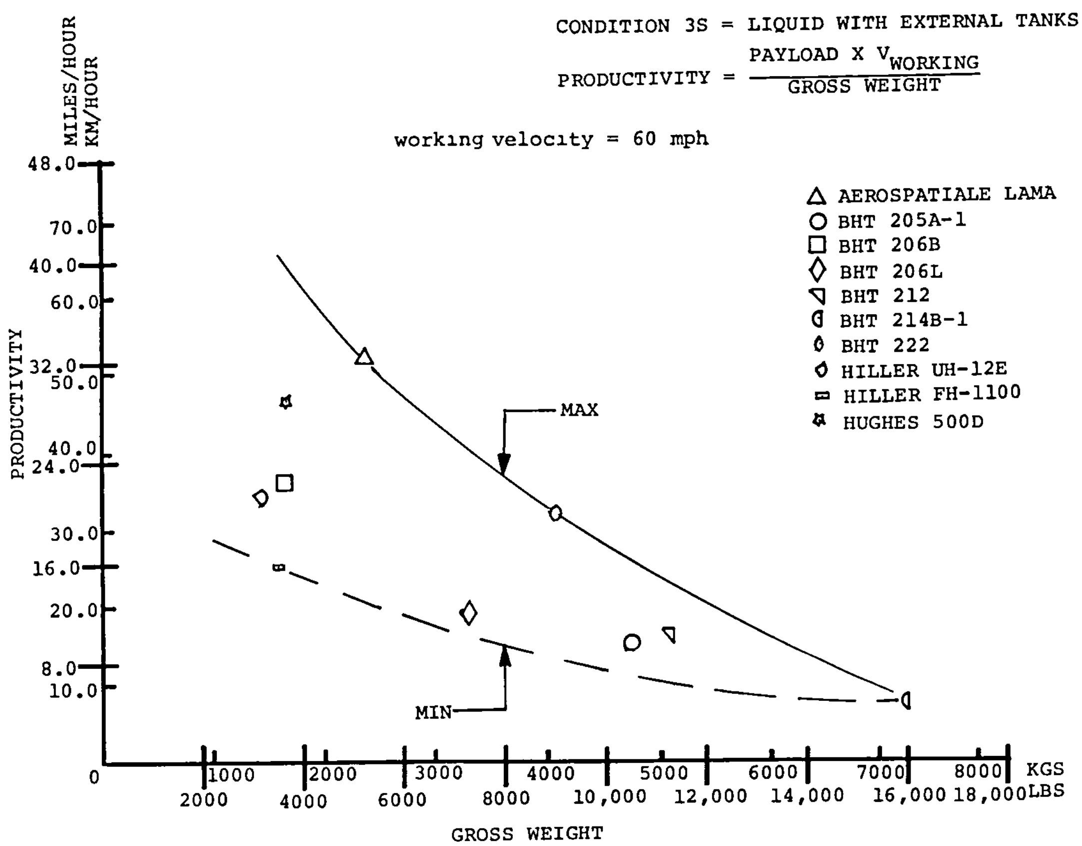

Figure B-3. Productivity vs gross weight, working velocity.

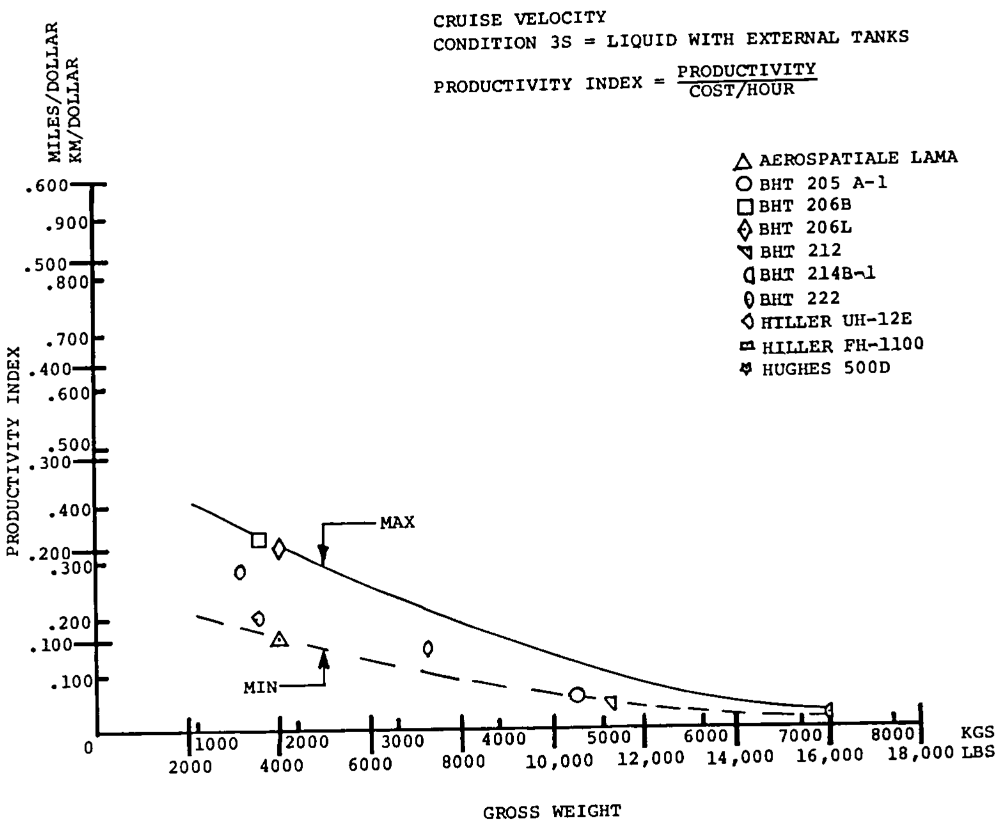

Figure B-4. Productivity vs gross weight, cruise velocity.

APPENDIX C

DISCUSSION ON ROTOR WAKES

A. VARIABILITY OF ROTOR WAKE WITH AIRSPEED

The helicopter will be considered in three basic conditions of flight as explained in Reference 13 . These conditions of flight are functions of airspeed and each range of airspeed presents its own unique rotor wake.

In the low-speed flight condition (hovering to 20 mph), the primary air movement is downward. Within this range, the helicopter rotor wake acquires a maximum downward velocity with maximum downward wake angle as shown in Figure 45. However, the averaging of downward velocities and wake angles are misleading without looking closely at a cross-section of the rotor wake.

The rotor imparts downward velocity to the air unevenly and in ever-increasing magnitude from the center of the rotor to the outboard end of the blade. Consequently, most of the total air movement in the rotor wake is confined to the outer portion of the rotating blade. The resulting air flow takes the shape of an annular ring, or doughnut, with an ineffective area in the center; extremely high velocity and large masses of air are moved in the tip area. This is very similar to the mass movement of a hurricane in that the central portion is calm while violent high-velocity air movement surrounds the eye. It is obvious that any spray material introduced into this central dead area would receive no benefit from the rotor wash. However, the concentration of force in the annular ring does allow for violent agitation of crop foliage; and if the air is supersaturated with liquid chemical, it contributes to good chemical coverage by thrashing the foliage in this saturated environment.

As the helicopter moves forward from a hover, this ring of violently agitated air becomes foreshortened and takes on the shape of an ellipse. Between the airspeeds of 18 to 22 mph, the minor axis of the elliptical air flow is diminished to zero length. This condition of flight is the point where translational lift is achieved.

As the helicopter increases speed beyond 20 mph, the annular ring effect is dissipated and a large mass of ill-defined air flow is generated, i.e., the "eye" of the hurricane has been closed in a multitude of small incremental air flows enjoined or opposed to each other in direction and in force. The air flow for practical purposes cannot decide whether to go downward or aft. It is a fairly homogeneous flow, all agitated, and the predominant air flow is downward.

With a forward speed of approximately 35 mph, the disturbed, ill-defined, agitated air flow assumes a well-defined and consistent pattern. The helicopter at this speed or greater is in forward flight, and the nature of the air flow generated by the helicopter assumes continuity (complex in nature). This complex flow is perhaps best presented graphically as in Figures C-1 and C-2. The cross-section of the air flow shown in Figure C-2 is taken approximately 60 feet behind the rotor; however, similar flow is available immediately behind the rotor and continues for great lengths behind the helicopter if left undisturbed by outside influences. Note that there are two exceptionally well-defined vortices of relatively large magnitude occurring behind the helicopter with an additional large amount of air being forced directly downward.

Each vortex, represented by the arrows arranged in a circular pattern, is a mass of air having a whirling or circular motion, tending to form a cavity or vacuum in the center of the circle. The length of the arrows indicate the relative velocity of the incremental air mass located at that particular point in the cross-section of the rotor wake. The arrows point to the direction in which the air is moving. The longest arrows are roughly equivalent to 12 mph airspeed and, as such, present no problem with respect to damaging fruit or foliage.

Additionally, at the point of origin, the center-to-center distance between the vortices is just under the rotor diameter (36.7 feet in this case) and slightly displaced from the centerline of the helicopter toward the retreating blade side. The average radius of the core is 3.62 feet. These may be visualized as two 7-foot diameter funnels extending rearward and downward.

Each vortex may be compared to the action of a whirlpool in that the outer rings of air are continuously being drawn toward the core or center cavity. Consequently, each vortex is held together for a relatively long period of time, and its action is sustained even after the helicopter has passed 1500 to 2500 feet beyond the initial point of contact. As a function of flying height and speed, these vortices can be directed into the foliage. They are fully developed in strength and direction within one rotor diameter behind the main rotor mast of the helicopter.

Without supplemental influencing factors such as ground obstruction, or the ground itself, these vortices, for practical purposes, would remain parallel to each other in space until

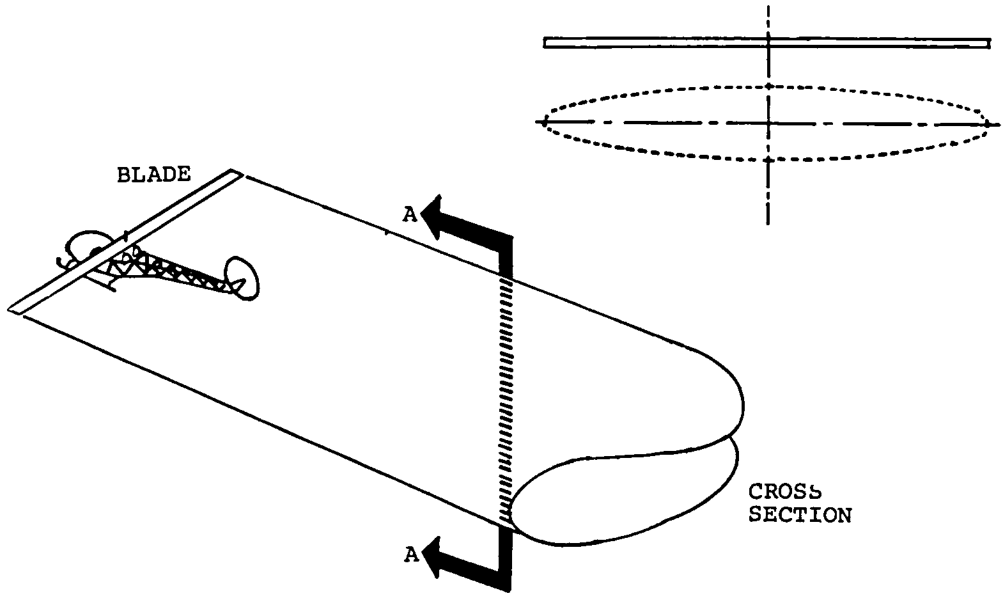

Figure C-1. Rotor wake.

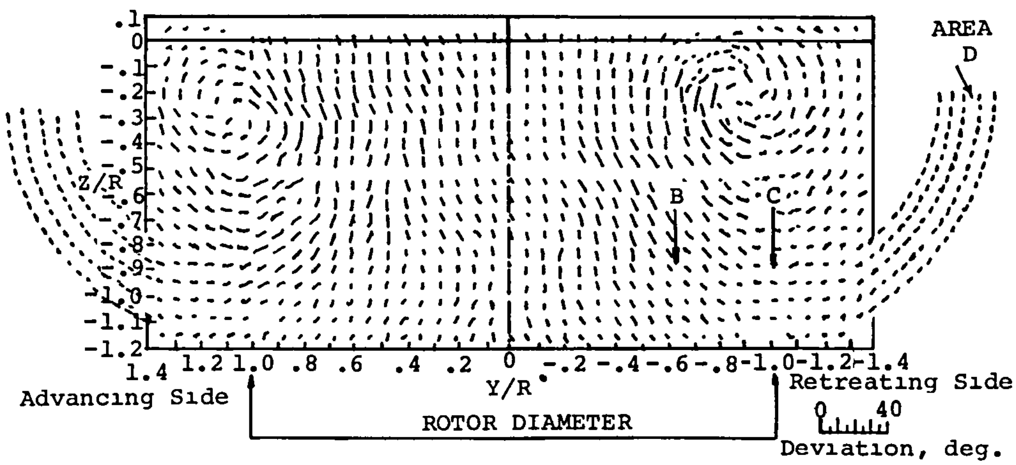

Figure C-2. Rotor wake cross section.

completely dissipated. However, when the helicopter is flown within 30 feet of the terrain, strong ground cushion effects are evidenced on the vortices, and they tend to repel each other and separate. The lower the helicopter is flown to the ground, the sooner the vortices will separate from each other. This is simply because the air has no other place to go. It is being accelerated downward and aft by the helicopter rotor in volumes greater than can be accommodated in these directions; therefore, the wake must expand laterally to dissipate its kinetic energy.

B. HARNESSING THE ROTOR WAKE

So far, this discussion has dealt only with basic helicopter characteristics to indicate it is a gigantic air blast machine which should be utilized to full advantage. Additionally, as most of the current work indicates a tendency towards increased liquid application in concentrate form, this continuing discussion will deal with liquid application in a broad form. It is not the intent to neglect or minimize the helicopter application of dust, seed, or granular material, but these applications are more selective in nature and require a wider variety of dispensing equipment specifically tailored to do a particular job, i.e., some seeding apparatus can be used for either dusting or granular dispensing, but usually not both.

- The entire spectrum of agricultural pesticide application is continuously changing with new developments in chemicals, crop control, equipment and application techniques.

- The crop pests are continuously changing in nature. Successful application of the present year may become inadequate in succeeding seasons.

- Even on the same crop, control techniques vary in different localities due to variances in climatic conditions, soil conditions, pest infestations, etc.

- Legislative regulations vary from locality to locality. What is legal and acceptable in one area may be prohibited in another.

- Fluctuating economic conditions quite often dictate the requirements of chemical application.

In the low airspeed (0 to 35 mph) flight regime, the helicopter plays a spcialist role. Helicopter maneuverability and agility to work in close spaces is a paramount asset. The rotor wake is sharply downward, and chemical drift is minimized. Typical work of this nature is characterized by herbicide application for selected brush control along a right-of-way where precise chemical control is mandatory. Swath width is controlled by the length of boom when booms are utilized for dispersal and distribution. In many instances, however, specialized dispensing equipment has been developed for specific chemicals or applications. Swath-width to boom-length ratios vary from 1 to 3.5 as a function of application. By using a large particle size (over 400 micron) in conjunction with a low flying height, the chemical application can be confined to the length of the boom. For this type of application, many operators prefer the boom located across the toes of the skids in full view of the pilot. As height above ground is increased, the swath width increases as well. Note that the effective swath is approximately 1.5 times the length of the boom and that good ground contact is achieved.

Another popular application using a helicopter low speed rotor wake is one that fogs a relatively large area. This is utilized in orchards in conjunction with extremely small particles emitted directly into the downward flowing rotor wake. Considerable agitation of the crop is also obtained to achieve overall coverage.

The low-speed aerial application range of the helicopter is often quite effective but is also the most costly due to production limiting low speeds and relatively narrow swath widths. By increasing both, higher productivity and corresponding lower costs per acre of application are possible. Surprisingly, however, quality of application as compared with the lower airspeeds need not be jeopardized, and in many instances is even improved. Increased speed and increased swath width are the two major contributing factors towards the reduced cost of application. This area of application is the most significant when dealing with volume of work and is representative of most of the available work.

To fully utilize the capabilities of the helicopter in this speed regime, three important parameters need to be understood. These are:

- Aerodynamic characteristics of the rotor wake in direction, volume, and velocity
- Impingement and carrying characteristics of liquid particles contained in a moving airflow
- Predistribution of liquid particles into the rotor wake prior to contact with the plant foliage

C. LOW-LEVEL SPRAY APPLICATION

For doing low-level work, such as cotton insecticide application, only the lower or bottom side of the rotor wake need be considered. This is best shown pictorially (see Figure C-3).

This diagram shows the liquid spray being dispensed from a conventional boom. The spray is emitted into the free airstream subjected only to slight gravitational forces. For example, liquid droplets with a specific gravity of 1.0 would take the following time to fall 10 feet in still air as a function of droplet size:

Diameter, Microns	Time, Seconds (Approx.)
400	.7
200	2.6
100	10.2
80	15.6
50	41.0

Consequently, a short period of time elapses from the moment the liquid is ejected into the free airstream until the droplets come into contact with the rotor wake. At 60 mph, the closure speed of the rotor wake catching up to the particles is 88 feet per second. Therefore, a boom located directly under and approximately 10 feet below the main rotor would put the particles roughly 60 to 80 feet forward of the rotor wake and allow approximately 0.8 second for distribution in the free airstream prior to making contact with the rotor wake. Note that a particle larger than 400 microns would be on the ground before being caught by the rotor wake if boom height above the ground is less than 10 feet. This characteristic is of importance for the precise application of volatile herbicides when drift control must be emphasized. Swath width in this latter case is basically confined to the length of the boom.

Conversely, particles of lesser size than 400 microns will enter the rotor wake and be redistributed within the rotor wake prior to making ground or plant foliage contact. Figure C-4 is a cross-section of the total airflow behind the helicopter, but only the lower portion of this airflow is utilized for the low-level work. This is the portion of the airflow immediately below the vortices and may be represented by a relatively thin sheet of air as shown in Figure C-5.

A cross-section (A-A) of this portion of the airflow has incremental air movements within the overall mass air movement

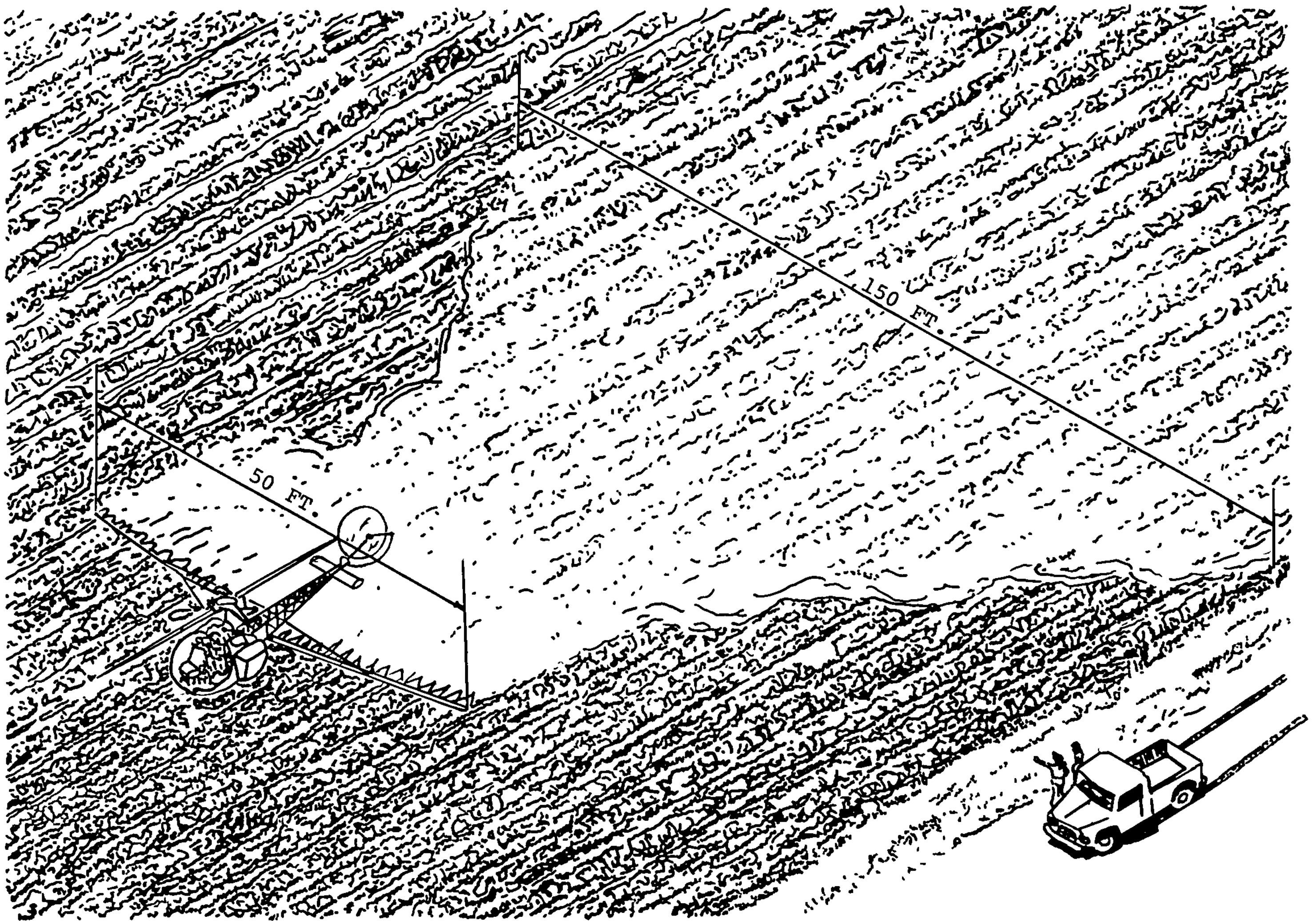

Figure C-3. Rotor wake/ground effect.

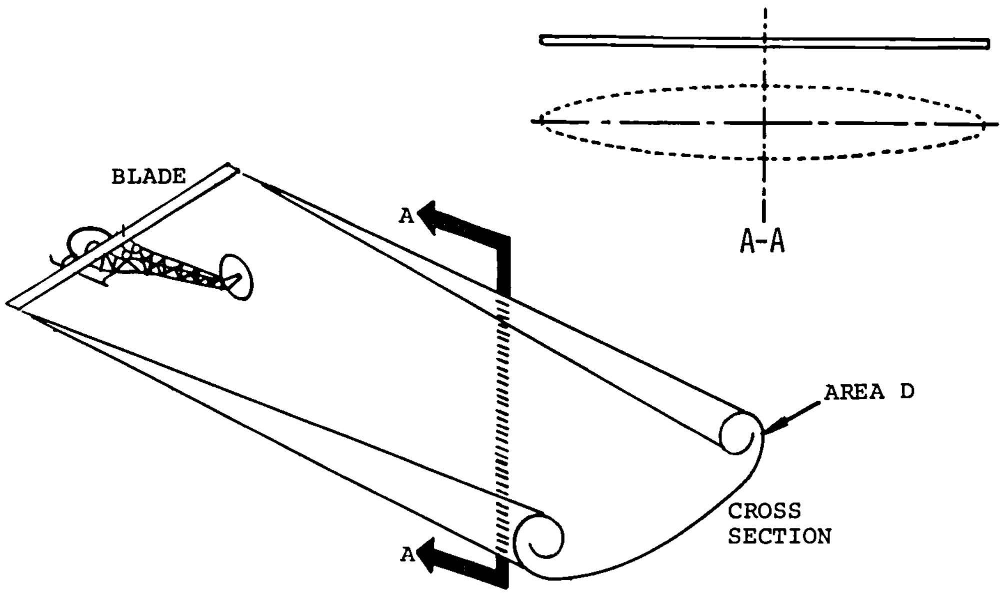

Figure C-4. Airflow cross section.

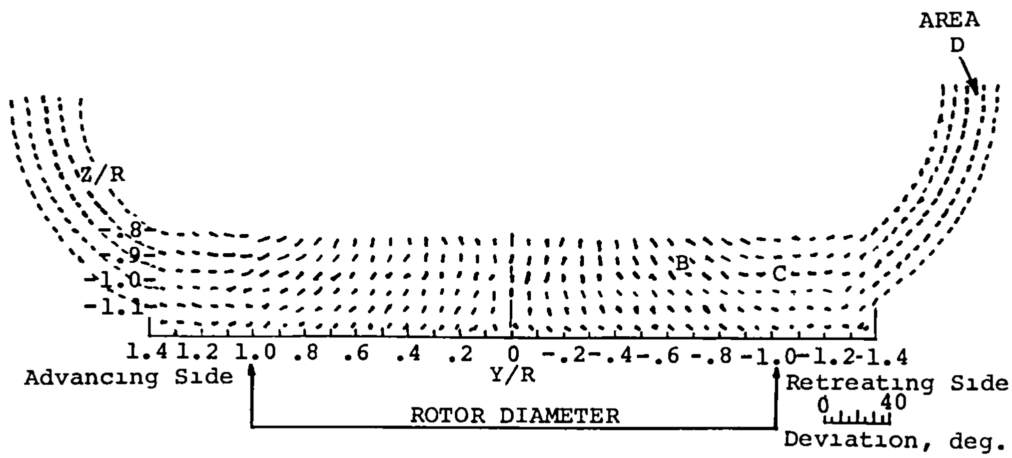

Figure C-5. Air sheet.

as shown in Figure 85; the entire mass of air is moving rearward and downward. Liquid particles introduced into these air currents will be carried with the airflow as a function of their size and specific gravity. Particles introduced at Point B and C will have a lateral velocity imparted until the force of gravity or the force of their momentum will eject them from the moving airstream.

Particular caution needs to be taken to assure that the particle size is large enough so that it is ejected before reaching approximately Point D. When the droplets become too small, they are then carried up into the vortices where their usefulness for low-level application is basically lost, resulting in "hot spots" in the distribution pattern or into an excessive drift problem. A properly adjusted spray system visually resembles Figure 84 in cross-section and, when flown over the crop, the extreme ends of the swath are the last to disappear into the foliage, therefore presenting a reliable, visual indication of swath width to the pilot.

The relationship of airflow, particle size, and predistribution for wide-swath low-level work may be summed as follows:

- Only the lower or bottom side of the rotor wake is used.

- Particle size selection is utilized to widen the swath but to avoid the vortices in the wake.

- Predistribution of the spray is required to introduce the material properly into the rotor wake in order to obtain an evenness of distribution.

D. HIGH-LEVEL SPRAY APPLICATION

High-level spray application is normally associated with orchard spraying where a more vertical distribution of spray is required than usually encountered in low-level spraying. Additionally, the requirement for leaf underside coverage is usually more severe. Consequently, an entirely different, although similar, technique of application is indicated. Contrary to the low-level approach where relatively little of the rotor wake is used and the vortices are avoided, high level work is characterized by maximum use of the total airflow and the vortices.

Particle size selection plays a most important part in obtaining adequate usefulness of the rotor wake. This type of application most closely resembles a concentrate mist blower in that air is used as the major diluent to carry and impinge the chemical. In order to achieve the best results, the following compromises must be made:

- If underside leaf coverage is required, the particles must be kept relatively small and be properly introduced into the vortices to remain in the rotor wake until contact is made with the foliage. Underside leaf coverage implies upward flowing air and this is obtainable only in the wake of the vortices or by turning the leaf with the force of the rotor wake.

- In order to effect impingement of the particle on an object, the droplet size must be maintained large enough to fall out of the air stream and impact while the air flows around the object.

The actual penetration for coverage of trees is even more complicated as a function of the density of the foliage. Smaller particles at higher velocities are required to penetrate dense foliage than are required for sparse foliage. But the denser foliage itself is a large detriment to maintaining the required higher velocities. It might be well to visualize a slow moving helicopter spraying a fine mist or a wet misty fog into a row of broad leaf trees. An observer watching this application would see a tree completely enshrouded with spray combined with a violent agitation of the leaves, limbs, and trunk. It is actually dramatic in appearance. Excellent coverage is anticipated, but after the action subsides, only a small amount of chemical has actually been deposited. This is due to the selection of too small a particle for efficient deposition. Usually, a fine mist spray is comprised of particles in the 10- to 50-micron size, with the larger portion of them less than 30 microns. By calculation, it can be shown that the wake velocity of the helicopter in this instance is approximately 30 mph, and additional calculation reveals that only particles in excess of 45-micron size would be efficiently deposited on a 3-inch wide object. However, if the tree were needle bearing instead of a broad leaf variety, excellent coverage would actually occur. The point to be stressed in this example is that there is a different optimum size particle or a range of particle sizes required for deposition in different types of foliage.

APPENDIX D

TABLE D-1. INPUT DATA

Design Gross Weight	3000 lb.
Flat Plate Drag Area	18 ft^2*
Main Rotor Diameter	33.33 ft
Tail Rotor Diameter	5.17 ft
Number of Blades (Main Rotor)	2
Number of Blades (Tail Rotor)	2
Tip Speed (Main Rotor)	688 ft/sec
Tip Speed (Tail Rotor)	690 ft/sec
Chord of Main Rotor	13 in.
Chord of Tail Rotor	5.25 in.
Airfoil Section (Main Rotor)	FX098
Airfoil Section (Tail Rotor)	FX098
Number of Engines	1
Engine Type	Allison C20
Rated Engine Shaft Horsepower	400
Rated Engine Specific Fuel Consumption	.640 lbs/shp/hr
Installation Loss for Power Available	7%
Main Transmission Continuous Power Rating	280 hp
Main Transmission Takeoff Power Rating	317 hp
Time Limit (Takeoff Transmission Rating)	30 min.
Limit Flight Load Factor	3.5
Vertical Crash Load Factor	16
Ultimate Landing Load Factor	3.75
Drive Speed	145 kts
Horizontal Tail Area	9.66 ft^2
Vertical Tail Area	9.32 ft^2
Length of Fuselage	17.25 ft
Maximum Fuselage Width	4.33 ft
Maximum Fuselage Height	4.33 ft
Length of Tailboom	13.9 ft
Fuselage Configuration	Cargo, Observation & Utility

*Flat plate drag area was varied to 13 ft^2 and 12 ft^2 for design improvement.

TABLE D-2. WEIGHT DATA

Cases 1 and 2

3,000 lb. Gross Weight

GHTS				% WE
WING GROUP			0	0.00
ROTOR GROUP			310	19.12
TAIL GROUP			48	2.94
VERTICAL		14		0.87
HORIZONTAL		14		0.86
VENTRAL FIN		11		0.66
TAIL ROTOR		9		0.56
BODY GROUP			401	24.77
FORWARD SECTION		251		15.49
TAILBOOM		34		2.10
WINDSHIELD		29		1.80
DOORS		44		2.73
CABIN FLOOR		43		2.65
SPONSONS		0		0.00
ALIGHTING GEAR			51	3.14
SKID GEAR		51		3.14
ENGINE SECTION/NACELLES			48	2.99
ENGINE SUPPORT		4		0.25
FIREWALLS		9		0.57
COWLING		26		1.61
AIR INLET SYSTEM		9		0.57
PROPULSION			386	23.86
ENGINE INSTALL		137		8.49
ACC G/B & DRIVE		0		0.00
EXHAUST SYSTEM		4		0.26
ENGINE COOLING		10		0.62
ENGINE CONTROL		11		0.66
STARTING SYSTEM		18		1.14
FUEL & LUBE SYSTEM		42		2.59
DRIVE SYSTEM		164		10.10
MAIN XMSN	107			6.59
MAST RETRACTION	0			0.00
FREE WHEELING	0			0.00
ROTOR BRAKE	8			0.50
T/R INTER. G.B.	0			0.00
T/R 90 GEARBOX	7			0.45
SPEED REDUCER G.B.	0			0.00
ENGINE INPUT SHAFT	9			0.58
M/R MAST	22			1.36
T/R DRIVE	10			0.62
FLIGHT CONTROLS			119	7.37
COCKPIT CONTROLS		21		1.31
SCAS		0		0.00
ROTATING CONTROLS		28		1.71
FIXED CONTROLS		70		4.35
ELEVATOR CONTROLS		0		0.00
APU			0	0.00
INSTRUMENTS			27	1.69
HYDRAULICS			25	1.52
ELECTRICAL			103	6.35
AVIONICS GROUP			26	1.64
ARMAMENT			0	0.00
FURNISHINGS & EQUIPMENT			50	3.09
AIR CONDITIONING			24	1.51
ANTI ICING GROUP			0	0.00
LOAD & HANDLING			0	0.00
WEIGHT EMPTY			1619	100.00

TABLE D-3. WEIGHT DATA

Case 3

3,000 lb. Gross Weight

				% WE
WEIGHTS				
WING GROUP			0	0.00
ROTOR GROUP			310	20.44
TAIL GROUP			39	2.58
VERTICAL		12		0.76
HORIZONTAL		11		0.75
VENTRAL FIN		9		0.58
TAIL ROTOR		7		0.49
BODY GROUP			329	21.73
FORWARD SECTION		206		13.59
TAILBOOM		28		1.84
WINDSHIELD		24		1.58
DOORS		36		2.39
CABIN FLOOR		35		2.33
SPONSONS		0		0.00
ALIGHTING GEAR			51	3.36
SKID GEAR		51		3.36
ENGINE SECTION/NACELLLES			48	3.20
ENGINE SUPPORT		4		0.26
FIREWALLS		9		0.61
COWLING		26		1.72
AIR INLET SYSTEM		9		0.61
PROPULSION			362	23.92
ENGINE INSTALL		137		9.07
ACC G/B & DRIVE		0		0.00
EXHAUST SYSTEM		4		0.28
ENGINE COOLING		10		0.66
ENGINE CONTROL		11		0.70
STARTING SYSTEM		18		1.22
FUEL & LUBE SYSTEM		47		3.13
DRIVE SYSTEM		134		8.86
MAIN XMSN	88			5.79
MAST RETRACTION	0			0.00
FREE WHEELING	0			0.00
ROTOR BRAKE	7			0.44
T/R INTER. G.B.	0			0.00
T/R 90 GEARBOX	6			0.39
SPEED REDUCER G.B.	0			0.00
ENGINE INPUT SHAFT	8			0.51
M/R MAST	18			1.19
T/R DRIVE	8			0.54
FLIGHT CONTROLS			119	7.88
COCKPIT CONTROLS		21		1.41
SCAS		0		0.00
ROTATING CONTROLS		28		1.83
FIXED CONTROLS		70		4.64
ELEVATOR CONTROLS		0		0.00
APU			0	0.00
INSTRUMENTS			27	1.81
HYDRAULICS			25	1.63
ELECTRICAL			103	6.78
AVIONICS GROUP			26	1.75
ARMAMENT			0	0.00
FURNISHINGS & EQUIPMENT			50	3.30
AIR CONDITIONING			24	1.61
ANTI ICING GROUP			0	0.00
LOAD & HANDLING			0	0.00
WEIGHT EMPTY			1515	100.00

TABLE D-4. WEIGHT DATA

Case 4

3,000 lb. Gross Weight

WEIGHTS				% WE
WING GROUP			0	0.00
ROTOR GROUP			310	19.81
TAIL GROUP			43	2.74
VERTICAL		13		0.81
HORIZONTAL		12		0.80
VENTRAL FIN		10		0.61
TAIL ROTOR		8		0.52
BODY GROUP			361	23.07
FORWARD SECTION		225		14.43
TAILBOOM		31		1.95
WINDSHIELD		26		1.68
DOORS		40		2.54
CABIN FLOOR		39		2.47
SPONSONS		0		0.00
ALIGHTING GEAR			51	3.26
SKID GEAR		51		3.26
ENGINE SECTION/NACELLES			48	3.10
ENGINE SUPPORT		4		0.26
FIREWALLS		9		0.59
COWLING		26		1.67
AIR INLET SYSTEM		9		0.59
PROPULSION			375	24.00
ENGINE INSTALL		137		8.80
ACC G/B & DRIVE		0		0.00
EXHAUST SYSTEM		4		0.27
ENGINE COOLING		10		0.64
ENGINE CONTROL		11		0.68
STARTING SYSTEM		18		1.18
FUEL & LUBE SYSTEM		47		3.02
DRIVE SYSTEM		147		9.41
MAIN XMSN	96			6.14
MAST RETRACTION	0			0.00
FREE WHEELING	0			0.00
ROTOR BRAKE	7			0.47
T/R INTER. G.B.	0			0.00
T/R 90 GEARBOX	7			0.42
SPEED REDUCER G.B.	0			0.00
ENGINE INPUT SHAFT	8			0.54
M/R MAST	20			1.27
T/R DRIVE	9			0.58
FLIGHT CONTROLS			119	7.64
COCKPIT CONTROLS		21		1.36
SCAS		0		0.00
ROTATING CONTROLS		28		1.77
FIXED CONTROLS		70		4.50
ELEVATOR CONTROLS		0		0.00
APU			0	0.00
INSTRUMENTS			27	1.76
HYDRAULICS			25	1.58
ELECTRICAL			103	6.58
AVIONICS GROUP			26	1.70
ARMAMENT			0	0.00
FURNISHINGS & EQUIPMENT			50	3.20
AIR CONDITIONING			24	1.57
ANTI ICING GROUP			0	0.00
LOAD & HANDLING			0	0.00
WEIGHT EMPTY			1562	100.00

TABLE D-5. WEIGHT DATA

Case 5

3,000 lb. Gross Weight

WEIGHTS				% WE
WING GROUP			0	0.00
ROTOR GROUP			310	21.30
TAIL GROUP			34	2.37
VERTICAL		10		0.70
HORIZONTAL		10		0.69
VENTRAL FIN		8		0.53
TAIL ROTOR		7		0.45
BODY GROUP			289	19.90
FORWARD SECTION		181		12.45
TAILBOOM		24		1.68
WINDSHIELD		21		1.45
DOORS		32		2.19
CABIN FLOOR		31		2.13
SPONSONS		0		0.00
ALIGHTING GEAR			51	3.50
SKID GEAR		51		3.50
ENGINE SECTION/NACELLES			48	3.34
ENGINE SUPPORT		4		0.28
FIREWALLS		9		0.63
COWLING		26		1.79
AIR INLET SYSTEM		9		0.64
PROPULSION			346	23.78
ENGINE INSTALL		137		9.46
ACC G/B & DRIVE		0		0.00
EXHAUST SYSTEM		4		0.29
ENGINE COOLING		10		0.69
ENGINE CONTROL		11		0.73
STARTING SYSTEM		18		1.27
FUEL & LUBE SYSTEM		47		3.22
DRIVE SYSTEM		118		8.11
MAIN XMSN	77			5.30
MAST RETRACTION	0			0.00
FREE WHEELING	0			0.00
ROTOR BRAKE	6			0.40
T/R INTER. G.B.	0			0.00
T/R 90 GEARBOX	5			0.36
SPEED REDUCER G.B.	0			0.00
ENGINE INPUT SHAFT	7			0.46
M/R MAST	16			1.09
T/R DRIVE	7			0.50
FLIGHT CONTROLS			119	8.21
COCKPIT CONTROLS		21		1.46
SCAS		0		0.00
ROTATING CONTROLS		28		1.90
FIXED CONTROLS		70		4.84
ELEVATOR CONTROLS		0		0.00
APU			0	0.00
INSTRUMENTS			27	1.89
HYDRAULICS			25	1.70
ELECTRICAL			103	7.07
AVIONICS GROUP			26	1.82
ARMAMENT			0	0.00
FURNISHINGS & EQUIPMENT			50	3.44
AIR CONDITIONING			24	1.68
ANTI ICING GROUP			0	0.00
LOAD & HANDLING			0	0.00
WEIGHT EMPTY			1453	100.00

TABLE D-6. WEIGHT DATA

Case 6

3,000 lb. Gross Weight

WEIGHTS				% WE
WING GROUP			0	0.00
ROTOR GROUP			310	22.24
TAIL GROUP			30	2.13
VERTICAL		9		0.63
HORIZONTAL		9		0.62
VENTRAL FIN		7		0.48
TAIL ROTOR		6		0.41
BODY GROUP			249	17.89
FORWARD SECTION		156		11.19
TAILBOOM		21		1.51
WINDSHIELD		18		1.30
DOORS		27		1.97
CABIN FLOOR		27		1.92
SPONSONS		0		0.00
ALIGHTING GEAR			51	3.66
SKID GEAR		51		3.66
ENGINE SECTION/NACELLES			48	3.48
ENGINE SUPPORT		4		0.29
FIREWALLS		9		0.66
COWLING		26		1.87
AIR INLET SYSTEM		9		0.66
PROPULSION			329	23.64
ENGINE INSTALL		137		9.87
ACC G/B & DRIVE		0		0.00
EXHAUST SYSTEM		4		0.31
ENGINE COOLING		10		0.72
ENGINE CONTROL		11		0.77
STARTING SYSTEM		18		1.33
FUEL & LUBE SYSTEM		47		3.36
DRIVE SYSTEM		102		7.30
MAIN XMSN	66			4.76
MAST RETRACTION	0			0.00
FREE WHEELING	0			0.00
ROTOR BRAKE	5			0.36
T/R INTER. G.B.	0			0.00
T/R 90 GEARBOX	4			0.32
SPEED REDUCER G.B.	0			0.00
ENGINE INPUT SHAFT	6			0.42
M/R MAST	14			0.98
T/R DRIVE	6			0.45
FLIGHT CONTROLS			119	8.57
COCKPIT CONTROLS		21		1.53
SCAS		0		0.00
ROTATING CONTROLS		28		1.99
FIXED CONTROLS		70		5.05
ELEVATOR CONTROLS		0		0.00
APU			0	0.00
INSTRUMENTS			27	1.97
HYDRAULICS			25	1.77
ELECTRICAL			103	7.38
AVIONICS GROUP			26	1.90
ARMAMENT			0	0.00
FURNISHINGS & EQUIPMENT			50	3.59
AIR CONDITIONING			24	1.76
ANTI ICING GROUP			0	0.00
LOAD & HANDLING			0	0.00
WEIGHT EMPTY			1392	100.00

TABLE D-7. WEIGHT DATA

Case 7

3,000 lb. Gross Weight

WEIGHTS				% WE
WING GROUP			0	0.00
ROTOR GROUP			310	20.62
TAIL GROUP			38	2.54
VERTICAL		11		0.75
HORIZONTAL		11		0.74
VENTRAL FIN		9		0.57
TAIL ROTOR		7		0.48
BODY GROUP			320	21.35
FORWARD SECTION		200		13.35
TAILBOOM		27		1.81
WINDSHIELD		23		1.55
DOORS		35		2.35
CABIN FLOOR		34		2.29
SPONSONS		0		0.00
ALIGHTING GEAR			51	3.39
SKID GEAR		51		3.39
ENGINE SECTION/NACELLES			48	3.23
ENGINE SUPPORT		4		0.27
FIREWALLS		9		0.61
COWLING		26		1.73
AIR INLET SYSTEM		9		0.62
PROPULSION			358	23.88
ENGINE INSTALL		137		9.16
ACC G/B & DRIVE		0		0.00
EXHAUST SYSTEM		4		0.28
ENGINE COOLING		10		0.67
ENGINE CONTROL		11		0.71
STARTING SYSTEM		18		1.23
FUEL & LUBE SYSTEM		47		3.13
DRIVE SYSTEM		131		8.70
MAIN XMSN	85			5.68
MAST RETRACTION	0			0.00
FREE WHEELING	0			0.00
ROTOR BRAKE	7			0.43
T/R INTER. G.B.	0			0.00
T/R 90 GEARBOX	6			0.39
SPEED REDUCER G.B.	0			0.00
ENGINE INPUT SHAFT	7			0.50
M/R MAST	18			1.17
T/R DRIVE	8			0.53
FLIGHT CONTROLS			119	7.95
COCKPIT CONTROLS		21		1.42
SCAS		0		0.00
ROTATING CONTROLS		28		1.84
FIXED CONTROLS		70		4.69
ELEVATOR CONTROLS		0		0.00
APU			0	0.00
INSTRUMENTS			27	1.83
HYDRAULICS			25	1.64
ELECTRICAL			103	6.84
AVIONICS GROUP			26	1.76
ARMAMENT			0	0.00
FURNISHINGS & EQUIPMENT			50	3.33
AIR CONDITIONING			24	1.63
ANTI ICING GROUP			0	0.00
LOAD & HANDLING			0	0.00
WEIGHT EMPTY			1501	100.00

TABLE D-8. INPUT DATA

Design Gross Weight	6000 lb.
Flat Plate Drag Area	20 ft^2*
Main Rotor Diameter	34 ft
Tail Rotor Diameter	6.5 ft
Number of Blades (Main Rotor)	2
Number of Blades (Tail Rotor)	2
Tip Speed (Main Rotor)	703 ft/sec
Tip Speed (Tail Rotor)	622 ft/sec
Chord of Main Rotor	28.6 in.
Chord of Tail Rotor	10 in.
Airfoil Section (Main Rotor)	FX098
Airfoil Section (Tail Rotor)	FX098
Number of Engines	2
Engine Type	LYCOMING LTS 101
Rated Engine Shaft Horsepower	650
Rated Engine Specific Fuel Consumption	.585 lbs/shp/hr
Installation Loss for Power Available	7%
Main Transmission Continuous Power Rating	850 hp
Main Transmission Takeoff Power Rating	1000 hp
Time Limit (Takeoff Transmission Rating)	30 min.
Limit Flight Load Factor	3.5
Vertical Crash Load Factor	8
Ultimate Landing Load Factor	3.75
Dive Speed	191 kts
Horizontal Tail Area	12.1 ft^2
Vertical Tail Area	17.4 ft^2
Length of Fuselage	24.4 ft
Maximum Fuselage Width	5.2 ft
Maximum Fuselage Height	5.2 ft
Length of Tailboom	10 ft
Fuselage Configuration	Cargo, Observation & Utility

* Flat plate drag area was varied to 14 ft^2 and 13 ft^2 for design improvement.

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TABLE D-9. WEIGHT DATA

Cases 1 and 2

6,000 lb. Gross Weight

WEIGHTS				% WE
WING GROUP			0	0.00
ROTOP GROUP			641	17.72
TAIL GROUP			82	2.26
VERTICAL		33		0.92
HORIZONTAL		24		0.65
VENTRAL FIN		0		0.00
TAIL ROTOR		25		0.69
BODY GROUP			889	24.60
FORWARD SECTION		689		19.07
TAILBOOM		54		1.50
WINDSHIELD		20		0.55
DOORS		70		1.94
CABIN FLOOR		56		1.54
SPONSONS		0		0.00
ALIGHTING GEAR			103	2.86
SKID GEAR		103		2.86
ENGINE SECTION/NACELLES			199	5.50
ENGINE SUPPORT		7		0.18
FIREWALLS		31		0.86
COWLING		115		3.19
AIR INLET SYSTEM		46		1.27
PROPULSION			1024	28.33
ENGINE INSTALL		462		12.79
ACC G/B & DRIVE		0		0.00
EXHAUST SYSTEM		11		0.31
ENGINE COOLING		19		0.53
ENGINE CONTROL		31		0.86
STARTING SYSTEM		37		1.02
FUEL & LUBE SYSTEM		40		1.12
DRIVE SYSTEM		423		11.70
MAIN XMSN	275			7.62
MAST RETRACTION	0			0.00
FREE WHEELING	0			0.00
ROTOR BRAKE	9			0.24
T/R INTER. G.B.	0			0.00
T/R 90 GEARBOX	18			0.49
SPEED REDUCER G.B.	0			0.00
ENGINE INPUT SHAFT	47			1.31
M/R MAST	54			1.51
T/R DRIVE	19			0.53
FLIGHT CONTROLS			336	9.31
COCKPIT CONTROLS		41		1.14
SCAS		29		0.80
ROTATING CONTROLS		95		2.63
FIXED CONTROLS		155		4.28
ELEVATOR CONTROLS		17		0.46
APU			0	0.00
INSTRUMENTS			41	1.15
HYDRAULICS			60	1.65
ELECTRICAL			164	4.53
AVIONICS GROUP			16	0.43
ARMAMENT			0	0.00
FURNISHINGS & EQUIPMENT			0	0.00
AIR CONDITIONING			0	0.00
ANTI ICING GROUP			0	0.00
LOAD & HANDLING			60	1.66
WEIGHT EMPTY			3614	100.00

TABLE D-10. WEIGHT DATA

Case 3

6,000 lb. Gross Weight

WEIGHTS				% WT.
WING GROUP			0	0.00
ROTOR GROUP			641	18.97
TAIL GROUP			67	1.99
VERTICAL		27		0.80
HORIZONTAL		19		0.57
VENTRAL FIN		0		0.00
TAIL ROTOR		21		0.61
BODY GROUP			730	21.62
FORWARD SECTION		566		16.76
TAILBOOM		44		1.32
WINDSHIELD		16		0.49
DOORS		58		1.70
CABIN FLOOR		46		1.35
SPONSONS		0		0.00
ALIGHTING GEAR			103	3.06
SKID GEAR		103		3.06
ENGINE SECTION/NACELLES			199	5.89
ENGINE SUPPORT		7		0.20
FIREWALLS		31		0.92
COWLING		115		3.41
AIR INLET SYSTEM		46		1.36
PROPULSION			959	28.41
ENGINE INSTALL		462		13.69
ACC G/B & DRIVE		0		0.00
EXHAUST SYSTEM		11		0.34
ENGINE COOLING		19		0.56
ENGINE CONTROL		31		0.92
STARTING SYSTEM		37		1.09
FUEL & LUBE SYSTEM		52		1.53
DRIVE SYSTEM		347		10.28
MAIN XMSN	226			6.70
MAST RETRACTION	0			0.00
FREE WHEELING	0			0.00
ROTOR BRAKE	7			0.21
T/R INTER. G.B.	0			0.00
T/R 90 GEARBOX	15			0.43
SPEED REDUCER G.B.	0			0.00
ENGINE INPUT SHAFT	39			1.15
M/R MAST	45			1.32
T/R DRIVE	16			0.47
FLIGHT CONTROLS			336	9.96
COCKPIT CONTROLS		41		1.22
SCAS		29		0.85
ROTATING CONTROLS		95		2.82
FIXED CONTROLS		155		4.58
ELEVATOR CONTROLS		17		0.49
APU			0	0.00
INSTRUMENTS			42	1.25
HYDRAULICS			60	1.77
ELECTRICAL			164	4.85
AVIONICS GROUP			16	0.46
ARMAMENT			0	0.00
FURNISHINGS & EQUIPMENT			0	0.00
AIR CONDITIONING			0	0.00
ANTI ICING GROUP			0	0.00
LOAD & HANDLING			60	1.78
WEIGHT EMPTY			3377	100.00

TABLE D-11. WEIGHT DATA

Case 4

6,000 lb. Gross Weight

WEIGHTS				% WE
WING GROUP			0	0.00
ROTOR GROUP			641	18.38
TAIL GROUP			74	2.11
VERTICAL		30		0.85
HORIZONTAL		21		0.61
VENTRAL FIN		0		0.00
TAIL ROTOR		23		0.65
BODY GROUP			799	22.94
FORWARD SECTION		620		17.79
TAILBOOM		49		1.40
WINDSHIELD		18		0.52
DOORS		63		1.81
CABIN FLOOR		50		1.43
SPONSONS		0		0.00
ALIGHTING GEAR			103	2.97
SKID GEAR		103		2.97
ENGINE SECTION/NACELLES			199	5.70
ENGINE SUPPORT		7		0.19
FIREWALLS		31		0.89
COWLING		115		3.30
AIR INLET SYSTEM		46		1.32
PROPULSION			992	28.46
ENGINE INSTALL		462		13.26
ACC G/B & DRIVE		0		0.00
EXHAUST SYSTEM		11		0.33
ENGINE COOLING		19		0.55
ENGINE CONTROL		31		0.90
STARTING SYSTEM		37		1.06
FUEL & LUBE SYSTEM		51		1.46
DRIVE SYSTEM		380		10.91
MAIN XMSN	248			7.11
MAST RETRACTION	0			0.00
FREE WHEELING	0			0.00
ROTOR BRAKE	8			0.22
T/R INTER. G.B.	0			0.00
T/R 90 GEARBOX	16			0.46
SPEED REDUCER G.B.	0			0.00
ENGINE INPUT SHAFT	42			1.22
M/R MAST	49			1.41
T/R DRIVE	17			0.49
FLIGHT CONTROLS			336	9.65
COCKPIT CONTROLS		41		1.18
SCAS		29		0.83
ROTATING CONTROLS		95		2.73
FIXED CONTROLS		155		4.44
ELEVATOR CONTROLS		17		0.48
APU			0	0.00
INSTRUMENTS			42	1.21
HYDRAULICS			60	1.71
ELECTRICAL			164	4.70
AVIONICS GROUP			16	0.45
ARMAMENT			0	0.00
FURNISHINGS & EQUIPMENT			0	0.00
AIR CONDITIONING			0	0.00
ANTI ICING GROUP			0	0.00
LOAD & HANDLING			60	1.72
WEIGHT EMPTY			3484	100.00

TABLE D-12. WEIGHT DATA

Case 5

6,000 lb. Gross Weight

WEIGHTS				% WL
WING GROUP			0	0.00
ROTOR GROUP			641	19.77
TAIL GROUP			59	1.82
VERTICAL		24		0.74
HORIZONTAL		17		0.53
VENTRAL FIN		0		0.00
TAIL ROTOR		18		0.56
BODY GROUP			641	19.78
FORWARD SECTION		497		15.34
TAILBOOM		39		1.21
WINDSHIELD		14		0.45
DOORS		51		1.56
CABIN FLOOR		40		1.24
SPONSONS		0		0.00
ALIGHTING GEAR			103	3.19
SKID GEAR		103		3.19
ENGINE SECTION/NACELLES			199	6.13
ENGINE SUPPORT		7		0.20
FIREWALLS		31		0.95
COWLING		115		3.55
AIR INLET SYSTEM		46		1.42
PROPULSION			920	28.40
ENGINE INSTALL		462		14.26
ACC G/B & DRIVE		0		0.00
EXHAUST SYSTEM		11		0.35
ENGINE COOLING		19		0.59
ENGINE CONTROL		31		0.96
STARTING SYSTEM		37		1.14
FUEL & LUBE SYSTEM		55		1.69
DRIVE SYSTEM		305		9.40
MAIN XMSN	199			6.13
MAST RETRACTION	0			0.00
FREE WHEELING	0			0.00
ROTOR BRAKE	6			0.19
T/R INTER. G.B.	0			0.00
T/R 90 GEARBOX	13			0.39
SPEED REDUCER G.B.	0			0.00
ENGINE INPUT SHAFT	34			1.05
M/R MAST	39			1.21
T/R DRIVE	14			0.43
FLIGHT CONTROLS			336	10.38
COCKPIT CONTROLS		41		1.27
SCAS		29		0.89
ROTATING CONTROLS		95		2.94
FIXED CONTROLS		155		4.77
ELEVATOR CONTROLS		17		0.51
APU			0	0.00
INSTRUMENTS			42	1.31
HYDRAULICS			60	1.84
ELECTRICAL			164	5.05
AVIONICS GROUP			16	0.48
ARMAMENT			0	0.00
FURNISHINGS & EQUIPMENT			0	0.00
AIR CONDITIONING			0	0.00
ANTI ICING GROUP			0	0.00
LOAD & HANDLING			60	1.85
WEIGHT EMPTY			3240	100.00

TABLE D-13. WEIGHT DATA

Case 6

6,000 lb. Gross Weight

WEIGHTS				% WE
WING GROUP			0	0.00
ROTOR GROUP			641	20.65
TAIL GROUP			51	1.64
VERTICAL		21		0.66
HORIZONTAL		15		0.47
VENTRAL FIN		0		0.00
TAIL ROTOR		16		0.50
BODY GROUP			552	17.80
FORWARD SECTION		428		13.80
TAILBOOM		34		1.09
WINDSHIELD		12		0.40
DOORS		43		1.40
CABIN FLOOR		34		1.11
SPONSONS		0		0.00
ALIGHTING GEAR			103	3.33
SKID GEAR		103		3.33
ENGINE SECTION/NACELLES			199	6.41
ENGINE SUPPORT		7		0.21
FIREWALLS		31		1.00
COWLING		115		3.71
AIR INLET SYSTEM		46		1.48
PROPULSION			878	28.31
ENGINE INSTALL		462		14.90
ACC G/B & DRIVE		0		0.00
EXHAUST SYSTEM		11		0.37
ENGINE COOLING		19		0.61
ENGINE CONTROL		31		1.01
STARTING SYSTEM		37		1.19
FUEL & LUBE SYSTEM		55		1.77
DRIVE SYSTEM		262		8.46
MAIN XMSN	171			5.52
MAST RETRACTION	0			0.00
FREE WHEELING	0			0.00
ROTOR BRAKE	5			0.17
T/R INTER. G.B.	0			0.00
T/R 90 GEARBOX	11			0.35
SPEED REDUCER G.B.	0			0.00
ENGINE INPUT SHAFT	29			0.95
M/R MAST	34			1.09
T/R DRIVE	12			0.38
FLIGHT CONTROLS			336	10.84
COCKPIT CONTROLS		41		1.32
SCAS		29		0.93
ROTATING CONTROLS		95		3.07
FIXED CONTROLS		155		4.98
ELEVATOR CONTROLS		17		0.54
APU			0	0.00
INSTRUMENTS			42	1.37
HYDRAULICS			60	1.92
ELECTRICAL			164	5.28
AVIONICS GROUP			16	0.50
ARMAMENT			0	0.00
FURNISHINGS & EQUIPMENT			0	0.00
AIR CONDITIONING			0	0.00
ANTI ICING GROUP			0	0.00
LOAD & HANDLING			60	1.93
WEIGHT EMPTY			3101	100.00

TABLE D-14. WEIGHT DATA

Case 7

6,000 lb. Gross Weight

WING GROUP			0	0.00
ROTOR GROUP			641	19.15
TAIL GROUP			65	1.95
VERTICAL		26		0.79
HORIZONTAL		19		0.56
VENTRAL FIN		0		0.00
TAIL ROTOR		20		0.60
BODY GROUP			710	21.23
FORWARD SECTION		551		16.46
TAILBOOM		43		1.29
WINDSHIELD		16		0.48
DOORS		56		1.67
CABIN FLOOR		44		1.33
SPONSONS		0		0.00
ALIGHTING GEAR			103	3.09
SKID GEAR		103		3.09
ENGINE SECTION/NACELLES			199	5.94
ENGINE SUPPORT		7		0.20
FIREWALLS		31		0.92
COWLING		115		3.44
AIR INLET SYSTEM		46		1.38
PROPULSION			950	28.39
ENGINE INSTALL		462		13.82
ACC G/B & DRIVE		0		0.00
EXHAUST SYSTEM		11		0.34
ENGINE COOLING		19		0.57
ENGINE CONTROL		31		0.93
STARTING SYSTEM		37		1.10
FUEL & LUBE SYSTEM		51		1.53
DRIVE SYSTEM		338		10.10
MAIN XMSN	220			6.58
MAST RETRACTION	0			0.00
FREE WHEELING	0			0.00
ROTOR BRAKE	7			0.21
T/R INTER. G.B.	0			0.00
T/R 90 GEARBOX	14			0.42
SPEED REDUCER G.B.	0			0.00
ENGINE INPUT SHAFT	38			1.13
M/R MAST	44			1.30
T/R DRIVE	15			0.46
FLIGHT CONTROLS			336	10.05
COCKPIT CONTROLS		41		1.23
SCAS		29		0.86
ROTATING CONTROLS		95		2.85
FIXED CONTROLS		155		4.62
ELEVATOR CONTROLS		17		0.50
APU			0	0.00
INSTRUMENTS			42	1.26
HYDRAULICS			60	1.78
ELECTRICAL			164	4.89
AVIONICS GROUP			16	0.47
ARMAMENT			0	0.00
FURNISHINGS & EQUIPMENT			0	0.00
AIR CONDITIONING			0	0.00
ANTI ICING GROUP			0	0.00
LOAD & HANDLING			60	1.79
WEIGHT EMPTY			3345	100.00

TABLE D-15. INPUT DATA

Design Gross Weight	12000 lb.
Flat Plate Drag Area	24 ft^2*
Main Rotor Diameter	48 ft
Tail Rotor Diameter	8.5 ft
Number of Blades (Main Rotor)	2
Number of Blades (Tail Rotor)	2
Tip Speed (Main Rotor)	746 ft/sec
Tip Speed (Tail Rotor)	736 ft/sec
Chord of Main Rotor	27 in.
Chord of Tail Rotor	8.4 in.
Airfoil Section (Main Rotor)	FX098
Airfoil Section (Tail Rotor)	FX098
Number of Engines	1
Engine Type	General Electric T700
Rated Engine Shaft Horsepower	1400
Rated Engine Specific Fuel Consumption	.469 lbs/shp/hr
Installation Loss for Power Available	7%
Main Transmission Continuous Power Rating	900 hp
Main Transmission Takeoff Power Rating	1100 hp
Time Limit (Takeoff Transmission Rating)	30 min.
Limit Flight Load Factor	3.5
Vertical Crash Load Factor	15
Ultimate Landing Load Factor	4.5
Dive Speed	220 kts
Horizontal Tail Area	10.5 ft^2
Vertical Tail Area	18.5 ft^2
Length of Fuselage	22.6 ft
Maximum Fuselage Width	3.17 ft
Maximum Fuselage Height	6.58 ft
Length of Tailboom	17.4 ft
Fuselage Configuration	Cargo, Observation & Utility

* Flat plate drag area was varied to 17 ft^2 and 16 ft^2 for design improvement cases.

TABLE D-16. WEIGHT DATA

Cases 1 and 2

12,000 lb. Gross Weight

WEIGHTS				% WE
WING GROUP			0	0.00
ROTOR GROUP			1228	20.51
TAIL GROUP			130	2.17
VERTICAL		64		1.06
HORIZONTAL		34		0.56
VENTRAL FIN		0		0.00
TAIL ROTOR		33		0.55
BODY GROUP			1131	18.88
FORWARD SECTION		769		12.84
TAILBOOM		165		2.75
WINDSHIELD		84		1.40
DOORS		57		0.96
CABIN FLOOR		56		0.94
SPONSONS		0		0.00
ALIGHTING GEAR			179	2.98
SKID GEAR		179		2.98
ENGINE SECTION/NACELLES			205	3.42
ENGINE SUPPORT		18		0.30
FIREWALLS		23		0.39
COWLING		111		1.86
AIR INLET SYSTEM		52		0.86
PROPULSION			1411	23.55
ENGINE INSTALL		538		8.98
ACC G/B & DRIVE		0		0.00
EXHAUST SYSTEM		10		0.16
ENGINE COOLING		25		0.42
ENGINE CONTROL		16		0.26
STARTING SYSTEM		29		0.48
FUEL & LUBE SYSTEM		109		1.82
DRIVE SYSTEM		684		11.42
MAIN XMSN	447			7.47
MAST RETRACTION	0			0.00
FREE WHEELING	10			0.17
ROTOR BRAKE	0			0.00
T/R INTER. G.B.	22			0.37
T/R 90 GEARBOX	33			0.56
SPEED REDUCER G.B.	0			0.00
ENGINE INPUT SHAFT	38			0.63
M/R MAST	96			1.60
T/R DRIVE	37			0.61
FLIGHT CONTROLS			306	5.10
COCKPIT CONTROLS		45		0.74
SCAS		48		0.80
ROTATING CONTROLS		124		2.07
FIXED CONTROLS		73		1.22
ELEVATOR CONTROLS		16		0.27
APU			0	0.00
INSTRUMENTS			118	1.98
HYDRAULICS			60	1.01
ELECTRICAL			198	3.31
AVIONICS GROUP			167	2.78
ARMAMENT			683	11.40
FURNISHINGS & EQUIPMENT			110	1.84
AIR CONDITIONING			63	1.06
ANTI ICING GROUP			0	0.00
LOAD & HANDLING			0	0.00
WEIGHT EMPTY			5989	100.00

TABLE D-17. WEIGHT DATA

Case 3

12,000 lb. Gross Weight

WEIGHT				% WE
WING GROUP			0	0.00
ROTOR GROUP			1228	21.77
TAIL GROUP			107	1.89
VERTICAL		52		0.93
HORIZONTAL		28		0.49
VENTRAL FIN		0		0.00
TAIL ROTOR		27		0.48
BODY GROUP			929	16.45
FORWARD SECTION		631		11.19
TAILBOOM		135		2.39
WINDSHIELD		69		1.22
DOORS		47		0.84
CABIN FLOOR		46		0.82
SPONSONS		0		0.00
ALIGHTING GEAR			179	3.17
SKID GEAR		179		3.17
ENGINE SECTION/NACELLES			205	3.62
ENGINE SUPPORT		18		0.32
FIREWALLS		23		0.41
COWLING		111		1.97
AIR INLET SYSTEM		52		0.92
PROPULSION			1291	22.87
ENGINE INSTALL		538		9.53
ACC G/B & DRIVE		0		0.00
EXHAUST SYSTEM		10		0.17
ENGINE COOLING		25		0.44
ENGINE CONTROL		16		0.28
STARTING SYSTEM		29		0.51
FUEL & LUBE SYSTEM		111		1.97
DRIVE SYSTEM		562		9.95
MAIN XMSN	367			6.51
MAST RETRACTION	0			0.00
FREE WHEELING	8			0.15
ROTOR BRAKE	0			0.00
T/R INTER. G.B.	18			0.33
T/R 90 GEARBOX	27			0.49
SPEED REDUCER G.B.	0			0.00
ENGINE INPUT SHAFT	31			0.55
M/R MAST	79			1.40
T/R DRIVE	30			0.53
FLIGHT CONTROLS			306	5.41
COCKPIT CONTROLS		45		0.79
SCAS		48		0.85
ROTATING CONTROLS		124		2.20
FIXED CONTROLS		73		1.29
ELEVATOR CONTROLS		16		0.28
APU			0	0.00
INSTRUMENTS			119	2.10
HYDRAULICS			60	1.07
ELECTRICAL			198	3.51
AVIONICS GROUP			167	2.95
ARMAMENT			683	12.10
FURNISHINGS & EQUIPMENT			110	1.95
AIR CONDITIONING			63	1.12
ANTI ICING GROUP			0	0.00
LOAD & HANDLING			0	0.00
WEIGHT EMPTY			5643	100.00

TABLE D-18. WEIGHT DATA 'A

Case 4

12,000 lb. Gross Weight

WEIGHTS				% WE
WING GROUP			0	0.00
ROTOR GROUP			1228	21.33
TAIL GROUP			117	2.03
VERTICAL		57		0.99
HORIZONTAL		30		0.53
VENTRAL FIN		0		0.00
TAIL ROTOR		29		0.51
BODY GROUP			1017	17.66
FORWARD SECTION		691		12.00
TAILBOOM		148		2.57
WINDSHIELD		75		1.31
DOORS		52		0.90
CABIN FLOOR		51		0.88
SPONSONS		0		0.00
ALIGHTING GEAR			179	3.10
SKID GEAR		179		3.10
ENGINE SECTION/NACELLES			205	3.56
ENGINE SUPPORT		18		0.31
FIREWALLS		23		0.41
COWLING		111		1.94
AIR INLET SYSTEM		52		0.90
PROPULSION			1309	22.73
ENGINE INSTALL		538		9.34
ACC G/B & DRIVE		0		0.00
EXHAUST SYSTEM		10		0.17
ENGINE COOLING		25		0.43
ENGINE CONTROL		16		0.28
STARTING SYSTEM		29		0.50
FUEL & LUBE SYSTEM		77		1.33
DRIVE SYSTEM		615		10.68
MAIN XMSN	402			6.99
MAST RETRACTION	0			0.00
FREE WHEELING	9			0.16
ROTOR BRAKE	0			0.00
T/R INTER. G.B.	20			0.35
T/R 90 GEARBOX	30			0.52
SPEED REDUCER G.B.	0			0.00
ENGINE INPUT SHAFT	34			0.59
M/R MAST	86			1.50
T/R DRIVE	33			0.57
FLIGHT CONTROLS			306	5.31
COCKPIT CONTROLS		45		0.77
SCAS		48		0.83
ROTATING CONTROLS		124		2.16
FIXED CONTROLS		73		1.27
ELEVATOR CONTROLS		16		0.28
APU			0	0.00
INSTRUMENTS			117	2.03
HYDRAULICS			60	1.05
ELECTRICAL			198	3.44
AVIONICS GROUP			167	2.89
ARMAMENT			683	11.86
FURNISHINGS & EQUIPMENT			110	1.91
AIR CONDITIONING			63	1.10
ANTI ICING GROUP			0	0.00
LOAD & HANDLING			0	0.00
WEIGHT EMPTY			5759	100.00

TABLE D-19. WEIGHT DATA

Case 5

12,000 lb. Gross Weight

WEIGHTS				% WE
WING GROUP			0	0.00
ROTOR GROUP			1228	22.53
TAIL GROUP			94	1.72
VERTICAL		46		0.84
HORIZONTAL		24		0.45
VENTRAL FIN		0		0.00
TAIL ROTOR		24		0.43
BODY GROUP			815	14.96
FORWARD SECTION		554		10.17
TAILBOOM		119		2.18
WINDSHIELD		60		1.11
DOORS		41		0.76
CABIN FLOOR		41		0.75
SPONSONS		0		0.00
ALIGHTING GEAR			179	3.28
SKID GEAR		179		3.28
ENGINE SECTION/NACELLES			205	3.75
ENGINE SUPPORT		18		0.33
FIREWALLS		23		0.43
COWLING		111		2.04
AIR INLET SYSTEM		52		0.95
PROPULSION			1225	22.47
ENGINE INSTALL		538		9.87
ACC G/B & DRIVE		0		0.00
EXHAUST SYSTEM		10		0.18
ENGINE COOLING		25		0.46
ENGINE CONTROL		16		0.29
STARTING SYSTEM		29		0.53
FUEL & LUBE SYSTEM		114		2.09
DRIVE SYSTEM		493		9.05
MAIN XMSN	323			5.92
MAST RETRACTION	0			0.00
FREE WHEELING	7			0.13
ROTOR BRAKE	0			0.00
T/R INTER. G.B.	16			0.30
T/R 90 GEARBOX	24			0.44
SPEED REDUCER G.B.	0			0.00
ENGINE INPUT SHAFT	27			0.50
M/R MAST	69			1.27
T/R DRIVE	26			0.49
FLIGHT CONTROLS			306	5.60
COCKPIT CONTROLS		45		0.82
SCAS		48		0.88
ROTATING CONTROLS		124		2.28
FIXED CONTROLS		73		1.34
ELEVATOR CONTROLS		16		0.29
APU			0	0.00
INSTRUMENTS			119	2.18
HYDRAULICS			60	1.10
ELECTRICAL			198	3.63
AVIONICS GROUP			167	3.05
ARMAMENT			683	12.53
FURNISHINGS & EQUIPMENT			110	2.02
AIR CONDITIONING			63	1.16
ANTI ICING GROUP			0	0.00
LOAD & HANDLING			0	0.00
WEIGHT EMPTY			5451	100.00

TABLE D-20. WEIGHT DATA

Case 6

12,000 lb. Gross Weight

WEIGHTS				% WE
WING GROUP			0	0.00
ROTOR GROUP			1228	23.35
TAIL GROUP			81	1.54
VERTICAL		40		0.75
HORIZONTAL		21		0.40
VENTRAL FIN		0		0.00
TAIL ROTOR		2[illegible]		0.39
BODY GROUP			702	13.35
FORWARD SECTION		476		9.08
TAILBOOM		102		1.94
WINDSHIELD		52		0.99
DOORS		36		0.68
CABIN FLOOR		35		0.67
SPONSONS		0		0.00
ALIGHTING GEAR			179	3.40
SKID GEAR		179		3.40
ENGINE SECTION/NACELLES			205	3.89
ENGINE SUPPORT		18		0.34
FIREWALLS		23		0.45
COWLING		111		2.12
AIR INLET SYSTEM		52		0.98
PROPULSION			1159	22.04
ENGINE INSTALL		538		10.23
ACC G/B & DRIVE		0		0.00
EXHAUST SYSTEM		10		0.19
ENGINE COOLING		25		0.48
ENGINE CONTROL		16		0.30
STARTING SYSTEM		29		0.55
FUEL & LUBE SYSTEM		117		2.22
DRIVE SYSTEM		425		8.07
MAIN XMSN	278			5.28
MAST RETRACTION	0			0.00
FREE WHEELING	6			0.12
ROTOR BRAKE	0			0.00
T/R INTER. G.B.	14			0.26
T/R 90 GEARBOX	21			0.39
SPEED REDUCER G.B.	0			0.00
ENGINE INPUT SHAFT	24			0.45
M/R MAST	60			1.13
T/R DRIVE	23			0.43
FLIGHT CONTROLS			306	5.81
COCKPIT CONTROLS		45		0.85
SCAS		48		0.91
ROTATING CONTROLS		124		2.36
FIXED CONTROLS		73		1.39
ELEVATOR CONTROLS		16		0.30
APU			0	0.00
INSTRUMENTS			119	2.26
HYDRAULICS			60	1.14
ELECTRICAL			198	3.76
AVIONICS GROUP			167	3.17
ARMAMENT			683	12.98
FURNISHINGS & EQUIPMENT			110	2.10
AIR CONDITIONING			63	1.21
ANTI ICING GROUP			0	0.00
LOAD & HANDLING			0	0.00
WEIGHT EMPTY			5260	100.00

TABLE D-21. WEIGHT DATA

Case 7

12,000 lb. Gross Weight

WEIGHTS				% WE
WING GROUP			0	0.00
ROTOR GROUP			1228	21.92
TAIL GROUP			104	1.86
VERTICAL		51		0.91
HORIZONTAL		27		0.48
VENTRAL FIN		[illegible]		[illegible]
TAIL ROTOR		26		0.47
BODY GROUP			904	16.13
FORWARD SECTION		614		10.96
TAILBOOM		131		2.35
WINDSHIELD		67		1.19
DOORS		46		0.82
CABIN FLOOR		45		0.81
SPONSONS		0		0.00
ALIGHTING GEAR			179	3.19
SKID GEAR		179		3.19
ENGINE SECTION/NACELLES			205	3.65
ENGINE SUPPORT		18		0.32
FIREWALLS		23		0.42
COWLING		111		1.99
AIR INLET SYSTEM		52		0.92
PROPULSION			1278	22.81
ENGINE INSTALL		538		9.60
ACC G/B & DRIVE		0		0.00
EXHAUST SYSTEM		10		0.18
ENGINE COOLING		25		0.45
ENGINE CONTROL		16		0.28
STARTING SYSTEM		29		0.52
FUEL & LUBE SYSTEM		114		2.04
DRIVE SYSTEM		546		9.75
MAIN XMSN	358			6.38
MAST RETRACTION	0			0.00
FREE WHEELING	8			0.14
ROTOR BRAKE	0			0.00
T/R INTER. G.B.	18			0.32
T/R 90 GEARBOX	27			0.48
SPEED REDUCER G.B.	0			0.00
ENGINE INPUT SHAFT	33			0.54
M/R MAST	77			1.37
T/R DRIVE	29			0.52
FLIGHT CONTROLS			306	5.45
COCKPIT CONTROLS		45		0.79
SCAS		48		0.86
ROTATING CONTROLS		124		2.22
FIXED CONTROLS		73		1.30
ELEVATOR CONTROLS		16		0.28
APU			0	0.00
INSTRUMENTS			119	2.12
HYDRAULICS			60	1.07
ELECTRICAL			198	3.53
AVIONICS GROUP			167	2.97
ARMAMENT			683	12.19
FURNISHINGS & EQUIPMENT			110	1.97
AIR CONDITIONING			63	1.13
ANTI ICING GROUP			0	0.00
LOAD & HANDLING			0	0.00
WEIGHT EMPTY			5603	100.00

APPENDIX E

LIST OF SYMBOLS

a	Swath length
AR	Aspect ratio of field $AR = \frac{w}{a}$ a = swath length w = length of field
C_D	Drag coefficient
C_P	Power coefficient
C_T	Thrust coefficient
D	Drag, kg or lbs
D_A	Drag, tube based on projected frontal area
D_F	Diameter fan
d	Fluid density lb/cu ft
E	Efficiency
F_R	Flow rate, gal/sec
H	Height of head, ft
HP	Horsepower, kw
L	Lift, kg or lbs
$L/_D$	Lift to drag ratio
N	Number of passes
P	Productivity $= \frac{\text{Payload x V}}{\text{Gross Weight}}$
P.I.	Productivity Index $= \frac{P}{\text{Operating cost/hr}}$
P.I.P	Productivity index product $= \frac{\text{P.I.}}{\text{Width of swath}}$
p	Pressure lb/sq in.
Q	Fluid quantity, cu ft/sec
r	Dispersal rate, gal/acre
S	Swath width

t	Turn time
V	Velocity, mph (km/hr)
V_{cruise}	Cruise speed of helicopter km/hr (mi/hr)
V_{max}	Maximum speed of helicopter km/hr (mph/hr)
$V_{working}$	Dispersal speed of helicopter km/hr (mph/hr)
W_e	Weight empty fraction $\frac{\text{\% Item Weigth}}{\text{Weight Empty}}$
W_f	Weight fraction
1S 2S 3S 4S	Spraying Condition (Reference Table 2-I)
1H 2H 3H 4H	Solids Dispersal Condition (Reference Table 2-I)
IGE	In ground effect
OGE	Out-of-ground effect
σ	Density ratio
ρ	Density of air
η	Pump/system efficiency, decimal

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15 Supplementary Notes

Langley Technical Monitor: Dr. Bruce J. Holmes

16 Abstract

A state-of-the-art study of helicopter aerial dispersal systems was conducted to ascertain constraints to the system, the effects of removal of limitations (technical and FAA regulations), and subsystem improvements. Productivity indices for the aircraft and swath effects were studied. Typical missions were formulated through conversations with operators, and differing gross weight aircraft were synthesized to perform these missions. Economic analysis of missions and aircraft indicated a general correlation of small aircraft (3000 lb gross weight) suitability for small fields (25 acres), and low dispersion rates (less than 32 lb/acre), with larger aircraft (12,000 lb gross weight) being more favorable for bigger fields (200+ acres) and heavier dispersal rates (100 lb/acre).

A review of operator problems, possible aircraft and system improvements, and selected removal of operating limitations were factored into recommendations for future NASA research items.

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