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Advanced System Design Requirements for Large & Small Fixed-Wing Aerial Application Systems for Agriculture

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FOREWORD

This report contains the results of a study of advanced design requirements for aerial application aircraft for agriculture. The study was conducted by the Lockheed-Georgia Company under contract to the Langley Research Center of the National Aeronautics and Space Administration. Dr. B. J. Holmes was the NASA technical manager.

At the Lockheed-Georgia Company, the study was performed under the cognizance of R. H. Lange, Manager of the Advanced Technology Systems Department. J. T. Hinely, Jr., served as study manager with R. Q. Boyles, Jr., as principal investigator for system design. Piper Aircraft Corporation and Mississippi State University participated in the program as subcontractors.

Measurement values used in this report are stated first in customary units with SI units following in parentheses. The principal measurements and calculations were performed in customary units.

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CONVERSION TO INTERNATIONAL (SI) UNITS

Customary Unit	International Unit	Conversion
feet (ft)	meter (m)	1 ft = 0.3048 m
acre (A)	hectare (ha)	1 A = 0.4047 ha
pound mass (lb) (avoirdupois)	kilogram (kg)	1 lb = 0.4536 kg
pound force (lbf) (avoirdupois)	newton (N)	1 lbf = 4.4482 N
gallon (gal)	liter (l)	1 gal = 3.7854 l
mile (mi)	kilometer (km)	1 mi = 1.6093 km
	nautical mile (nm)	1 mi = 0.8690 nm
horsepower (HP)	kilowatt (kw)	1 HP = 0.7457 kw
\$/A	\$/ha	1 \$/A = 2.471 \$/ha
lb/A	kg/ha	1 lb/A = 1.1208 kg/ha
gal/A	l/ha	1 gal/A = 9.3536 l/ha
acres/hour (A/hr)	ha/hr	1 A/hr = 0.4047 ha/hr
miles/hour (mph)	knots (kt)	1 mph = 0.8690 kt
	km/hr	= 1.6093 km/hr
ft/sec(s)	m/s	1 ft/s = 0.3048 m/a
lb/sec(s)	kg/s	1 lb/s = 0.4536 kg/s
psi (lbf/in^2)	newtons/m^2 (N/m^2)	1 psi = 6.8948 kN/m^2
lb/sq ft (ft^2)	kg/m^2	1 lb/ft^2 = 4.8827 kg/m^2
lb/ft^3	kg/m^3	1 lb/ft^3 = 16.0282 kg/m^3
lb/in^3	kg/m^3	1 lb/in^3 = 27680 kg/m^3
cu ft (ft^3)	m^3	1 ft^3 = 0.0283 m^3

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SUMMARY

OBJECTIVES AND APPROACH

The objectives of the study were to evaluate current state-of-the-art for agricultural aircraft design, with emphasis on design concepts that offer potential for improved productivity, economics, and safety; identify areas requiring additional research; evaluate airworthiness regulations; and illustrate promising design concepts. The approach was to develop conventional baseline design configurations for one large aircraft and one small aircraft and to evaluate aircraft and subsystem technology concepts in comparison with the baselines. An operations analysis model was used to obtain quantitative measures of mission productivity and economics for the design concepts under consideration.

SYSTEM CONFIGURATION DEVELOPMENT

Several candidate aircraft configurations were defined over the range of 1000 to 10,000 pounds payload (454 to 4536 kg) and evaluated over a broad spectrum of agricultural missions. From these studies, baseline design points were selected at 3200 pounds (1452 kg) payload for the small aircraft and 7500 pounds (3402 kg) for the large aircraft. The small baseline aircraft utilizes a single turboprop powerplant while the large aircraft utilizes two turboprop powerplants.

These configurations were optimized for wing loading, aspect ratio, and power loading to provide the best mission economics in representative missions. Wing loading of 20 lb/sq ft (97.7 kg/sq m) was selected for the small aircraft and 25 lb/sq ft (122.1 kg/sq m) for the large aircraft. Aspect ratio of 8 was selected for both aircraft. It was found that a 10% reduction in engine power from the original configurations provided improved mission economics for both aircraft by reducing the cost of the turboprop engines. Refined configurations incorporate a 675 HP (503 kw) engine in the small aircraft and two 688 HP (513 kw) engines in the large aircraft.

Parametric sensitivity studies were conducted for major design characteristics to determine effects on mission productivity and cost. It was found that the effects of design characteristics are greatly dependent on the type of missions being performed. Increased swath width provides good productivity improvements with low application rates but is less important for high-application missions. Reduced turn time has a similar effect, with greater benefit in small fields. Reduced structural weight is important and becomes increasingly beneficial with higher application rates. Ferry speed is quite significant in all cases, but increasingly so with longer ferry distances and/or higher application rates. Best design trade-offs for future aircraft will depend on the markets the aircraft are intended to serve.

The external drag of liquid dispersal systems has a strong detrimental effect on mission productivity because it reduces ferry speed. Low-drag dispersal system designs are recommended such as incorporation of the spray boom in trailing edge flaps. Pumping efficiency of current liquid systems is adequate for low-volume liquid applications but needs to be increased for improved productivity in higher application missions.

From the limited test data available, it appears that the high drag of conventional dry material spreaders seriously inhibits the productivity of aircraft in dry material missions such as fertilizer applications. Major improvements are needed in dry dispersal systems if aerial methods are to become more competitive for this type work. Free release of dry materials appears to offer advantages at higher application rates, and this approach deserves further investigation. The benefits of free release increase with multiple dispersal points along the wing, and investigations should be made of concepts for dry material transport through the wing to dispersal points along the wing span. Mechanical spreaders also appear to be promising from the limited data available.

Several alternate aircraft concepts were examined during the course of the study. A twin reciprocating engine aircraft with the same gross weight as the small baseline aircraft was evaluated to see if the lower cost of engines would improve mission economics. The aircraft was found to be non-competitive, however, because of increased empty weight, which caused a reduction in payload, and because of reduced engine performance. A turbo-fan version of the small aircraft was also found to be non-competitive because of high fuel consumption and the high cost of the engine.

An advanced biplane version of the large baseline aircraft was found to offer possible advantages. This aircraft concept incorporates a lower wing that is unloaded during swath runs but with flaps for added lift during takeoff and turns. The spray boom and plumbing are enclosed in the lower wing for low drag, and the dispersal system is separated from the tip vortex of the loaded upper wing. The aircraft has dual hoppers, one mounted on each wing to the rear of the engines. Limited analysis of this configuration concept indicates that mission costs are higher than the conventional baseline aircraft in most missions, but the concept shows promise and is considered to merit more detailed study.

STRUCTURES AND MATERIALS

Composite materials for agricultural aircraft structure show promise both for weight reduction and corrosion reduction. An all-composite aircraft of the same size as the small baseline aircraft was defined conceptually and evaluated for weight reduction potential. The aircraft uses a high degree of fiberglas and Kevlar with graphite/epoxy reinforcement. Although the analysis was limited in depth, the composite aircraft is indicated as being economically competitive with the baseline metal aircraft. A configuration with a composite wing of aspect ratio 10 and conventional metal structure in other areas was found to be superior to the baseline aircraft in mission economics. Composite materials configurations deserve further study.

Composite materials are inherently corrosion resistant and may offer near-term benefits for corrosion reduction in selected applications with current aircraft. More information is needed on the effects of agricultural chemicals on composite materials. Laboratory testing is recommended for this purpose, and a field service test with one or more current aircraft in normal operation is also recommended. The underside of the fuselage is a high-corrosion area, and belly skins fabricated of composites would be a good application for the service test.

AIRCRAFT CONTROL SYSTEMS

There are no standard design criteria for stability and control characteristics of agricultural aircraft, and flight tests and/or piloted simulations are needed to develop handling qualities data as a basis for design guidelines. Mechanical control systems are considered adequate for these aircraft, although powered systems offer advantages for tailoring stick and pedal forces for optimum handling qualities.

Direct lift control in the form of a flap system is strongly recommended in future aircraft for reduced takeoff distance and improvements in turn time. Direct drag control beyond that available with flaps and turboprop pitch control does not appear to be warranted. Direct side force control is considered to introduce excessive complexities for marginal mission benefits and does not merit further consideration in the near future.

MISSION ANALYSIS

Mission productivity and cost analyses were performed with the operations analysis model throughout the study for evaluation of design concepts. Extensive data were generated for the refined baseline aircraft in a variety of missions. The small aircraft was shown to have good economics over a wide range of missions for both liquid and dry material dispersal. The large aircraft is attractive in high-volume liquid missions, but the high drag of conventional dry material spreaders inhibits the productivity of the aircraft in dry missions. Consequently, the large aircraft appears to be of limited utility in crop work unless improved dry dispersal methods are developed. Additional studies should be made of wide-area missions.

It was not possible in the present study to provide a valid economic comparison between the study aircraft and currently existing agricultural aircraft. A rough comparison was made by representing two present-day aircraft in the operations analysis model for the same missions used for the study aircraft. The results indicate that the small baseline aircraft defined in the study is far superior to very small current aircraft except for low application rates in small fields. The small study aircraft is indicated to have better mission economics than a current large radial-engine aircraft over the entire mission spectrum, with the advantage ranging from about 10% to 30% depending on field size and application rate.

SAFETY, OPERATIONAL, AND REGULATORY

Established design concepts for agricultural aircraft safety were incorporated in all aircraft configurations considered in the study. An assessment was made of electronic swath guidance concepts for improved operational utility, with the conclusion that flight testing of candidate systems is necessary to determine suitability for the agricultural mission. An evaluation was made of airworthiness regulations to determine if research is needed to support regulatory changes.

It was concluded that inadequacies exist in present airworthiness regulations for agricultural aircraft. Present regulations are not definitive in several areas, do not recognize the mission-dedicated nature of agricultural aircraft in other areas, and do not fully reflect current design technology. Research is needed in specific areas, and regulatory changes are needed to clarify specific requirements. It is recommended that a task group be formed to draft a new FAR part for agricultural aircraft.

CONCLUSIONS AND RECOMMENDATIONS

The following concepts offer promise for improved productivity of agricultural aircraft and are considered to merit additional investigation:

- Advanced biplane concept with unloaded lower wing.
- Low-drag liquid dispersal systems.
- Free-release method of dispersing dry materials.
- Multiple hopper designs.
- Dry material dispersal along the wing.
- Composite materials for aircraft structure.

In addition to the above concepts, research is recommended in the following areas:

- Additional aircraft studies to refine promising system concepts.
- Particle-in-wake behavior and swath prediction.
- Experimentation with dry material dispersal concepts.
- Flight tests and simulations for handling qualities.
- Guidance system evaluations.
- Research and development to support regulatory changes.

1.0 INTRODUCTION

Aircraft play an important role in application of agricultural chemicals and other materials both in the U.S. and a number of foreign countries. Aerial methods presently account for a relatively small portion of overall agricultural materials application requirements, however, and there is potential for expansion into a much broader market area with improved aerial systems. Present agricultural aircraft were derived primarily from other aircraft designs and basically reflect general aviation design technology of an earlier period. Dispersal systems have changed very little in the past 20 years.

It is timely and appropriate for NASA to conduct a broad-based research effort to support the development of improved aerial application systems. Technology areas of interest to NASA in this effort are closely related to a number of Lockheed's on-going research and development programs, and the Lockheed-Georgia Company was pleased to conduct the present design study for NASA's Langley Research Center. Lockheed-Georgia has conducted independent development studies of agricultural aircraft design requirements over the past two years, and much of the data and methodology employed in the present study are direct results of this independent program.

The present study is a combined analysis of large and small fixed-wing agricultural aircraft, in compliance with NASA Statements of Work 1-05-3640.0136A and 1-05-3640.0136B. Large aircraft were defined by NASA to fall within the payload range of 3000 to 10,000 pounds (1360.8 to 4536.0 kg), and small aircraft to fall within the payload range of 1000 to 4000 pounds (453.6 to 1814.4 kg). Parametric studies were performed to select one baseline design point in each of these two categories, with more detailed analysis conducted for the two baseline aircraft to examine applications of current and emerging design technology. Technology deemed to be available by 1985 was considered in the study.

An integrated systems analysis approach was employed with consideration of the combined effects of aircraft dispersal systems, material loading, and various mission conditions on overall system effectiveness. Major use was made of a computerized operations analysis model to evaluate design concepts in terms of mission productivity and economics in simulated aerial application missions.

2.0 STUDY APPROACH

2.1 STUDY OBJECTIVES

The objectives of this study were specified by NASA as follows:

- Evaluate the state-of-the-art, particularly in aircraft design, as applicable to agricultural aircraft;

- Identify topics and areas requiring more research. Biological or agronomic topics were not to be considered except as potential markets influence aircraft design and operations;

- Evaluate regulatory and certification requirements as applicable to design and operations and recommend changes if deemed desirable or necessary;

- Propose and illustrate design configurations.

2.2 STUDY GUIDELINES

The guidelines established with NASA for the combined study of large and small fixed-wing aircraft are given below.

- Minimum no-payload ferry range will be at least 300 n.m.

- Endurance in terms of fuel capacity will not be constrained. Effects of fuel capacity on the mission will be examined.

- Swath speed will not be constrained.

- Payloads for small aircraft configurations may range from 1000 to 4000 pounds (453.6 to 1814.4 kg) and for large aircraft configurations from 3000 to 10,000 pounds (1360.8 to 4536.0 kg).

- Load density of 33 to 100 pounds per cubic foot (528.9 to 1602.8 kg/cu m) will be considered.

- Material application rates may vary from .89 to 1000 pounds per acre (1.0 to 1120.8 kg/ha).

- For the purpose of the study, it may be assumed that size distribution for liquid and dry particles is controllable to the degree desired. This assumption does not obviate any system design considerations pertaining to control of drift and of distribution uniformity within the swath. The assumption is made to allow study emphasis to be focused on matters other than the detailed design of dispersal equipment, such as nozzles.

- Aircraft performance computations will be referenced to both Standard Day and Hot Day Conditions.

- Rough unimproved airstrips are to be considered in the study. Economic effects of operating from smooth or unimproved fields will be identified. Airstrips will be considered to have 50 foot (15.2 m) obstacles at approach and takeoff boundaries.

- The Federal Aviation Regulations (FAR's) and Civil Aviation Manuals (CAM's) may serve as general guidelines for airworthiness and operating requirements in the design study. The contractor is to specify any inadequacies in existing regulations and suggest areas of research which would provide data to support recommended regulation changes.

2.3 STUDY PLAN

The basic technical approach for the study program is shown in the diagram of Figure 1. Based on the NASA guidelines, a number of candidate aircraft configurations were defined for initial evaluation. These configurations varied in payload and hopper size so as to span the entire range of capabilities specified in the guidelines for large and small aircraft.

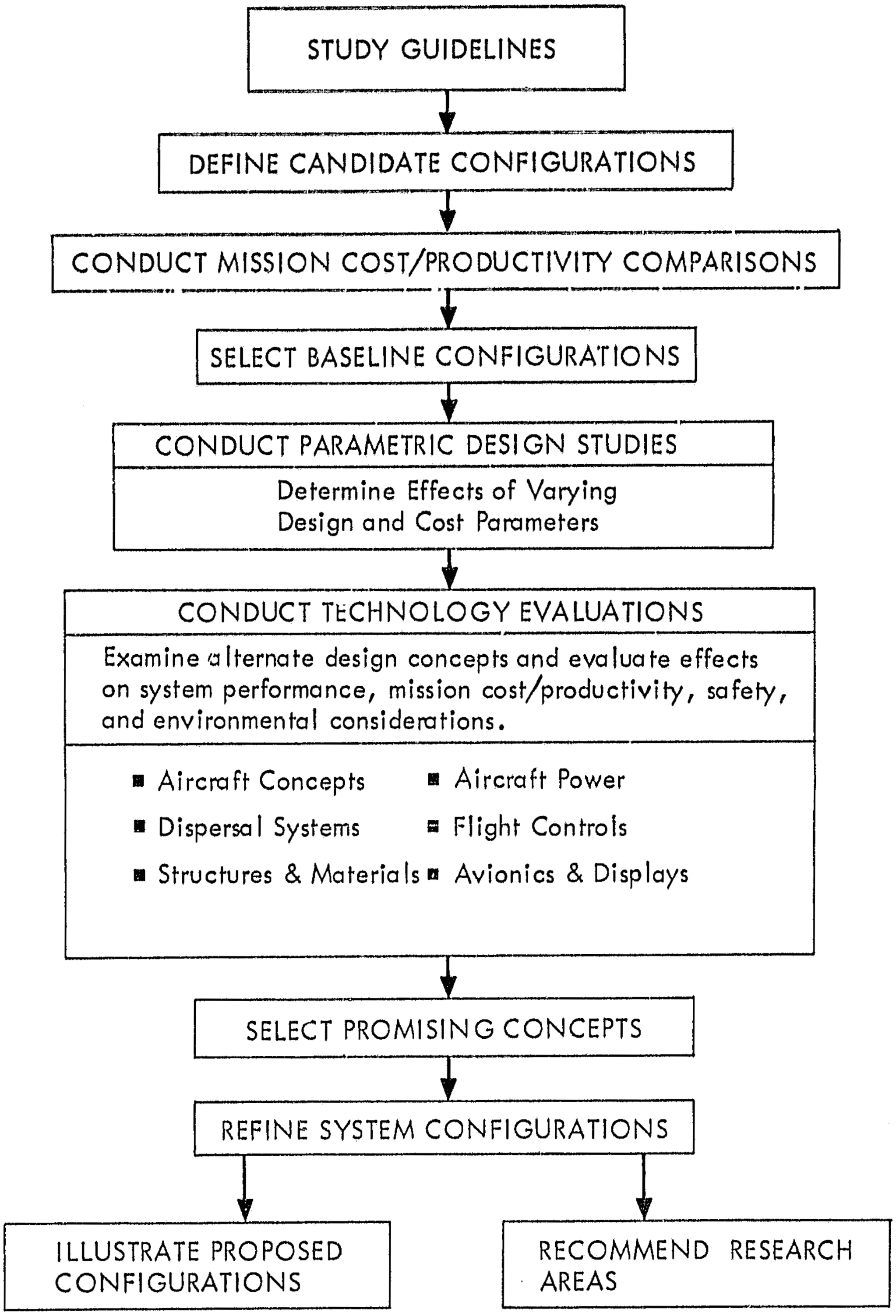


Figure 1. Study Approach

The candidate configurations were developed conceptually as conventional state-of-the-art monoplane designs similar to existing agricultural aircraft. Using the Lockheed aerial application operations analysis model, mission cost and productivity comparisons were performed for the candidate configuratuions over the range of mission parameters stated in the guidelines. From these data, two design points were selected as the baseline study configurations. One baseline design point was selected within the payload range specified for small aircraft, and the second baseline point was selected within the payload range for large aircraft.

Parametric design studies were conducted to refine the baseline configurations with respect to wing loading, aspect ratio, and power loading. This was accomplished by varying the baseline design over a range of parametric values and evaluating the resulting effects on mission cost and productivity. The baseline designs were modified as appropriate in each case to provide the best mission economics.

A series of parametric sensitivity st ies were performed for the baseline configurations to examine the effects of varying design and cost parameters. Two types of sensitivities were examined: (1) sensitivity of mission cost and productivity to various design characteristics; and (2) sensitivity of mission costs to the different system cost elements. This was accomplished by varying individual parameters one at a time in the operations analysis model and simulating representative missions to determine resulting effects. These data indicate the design areas and cost elements offering greatest potential payoffs for improved future agricultural aircraft.

Using the sensitivity data for guidance, investigations were made of current state-of-the-art and emerging technologies offering possible system improvements over the conventional baseline designs. Technology investigations encompassed alternate aircraft concepts matched to different types and number of power plants; dispersal systems; structural concepts; flight controls; and avionics systems for guidance and control. An effort was made in each of these areas to identify promising concepts and associated performance characteristics achievable with expected technology through 1985.

So far as possible, concepts judged to offer economic or operational merit were specifically evaluated against the baseline configurations in terms of cost and productivity in agricultural missions. Qualitative evaluations were made of safety, environmental, and operational effects that could not be specifically related to mission cost and productivity. Through this process, promising concepts were incorporated into refined configurations for the baseline design points, and mission cost and performance data were developed for the final baseline configurations over a wide range of missions. The results of these evaluations were then used as a basis for recommending future research areas.

Federal Aviation Regulations (FAR's) and Civil Aeronautics Manual (CAM) 8 were used as guidelines for the design studies, along with consideration of current and future agricultural aviation operations. A review was made of airworthiness regulations to determine if research is needed to support regulatory changes.

2.4 ADVISORY COMMITTEE

An Advisory Committee was formed for the study program to provide guidance and assistance to the contractor study team on matters relating to aerial application missions and operational considerations, aircraft design concepts, desirable capabilities for increased aircraft utility, and regulatory considerations. The committee played an important role in evaluating design concepts in areas where quantitative assessment of mission cost and productivity was not possible. The committee was also instrumental in the development of recommendations for additional research, particularly for research to support changes in airworthiness regulations.

Members of the Advisory Committee are listed on the next page.

H. W. Barnhouse
Director of Engineering
Piper Aircraft Corporation
Vero Beach, Florida

Paul M. Nichols
Vice President, Engineering
Ayres Corporation
Albany, Georgia

Dr. E. J. Cross
Director, Raspet Flight Research Lab.
Mississippi State University

Hugh Wheelless, Jr.
General Manager
Dothan Aviation
Dothan, Alabama

Stewart Kimmel
President, Kimmel Aviation
Greenwood, Mississippi

The following Piper Aircraft engineering personnel also participated in Advisory Committee meetings:

F. B. O'Donnell, Jr., Assistant Chief Engineer
J. D. Patrick, Chief Flight Test Engineer
C. Diefendorf, Engineering Program Manager.

3.0 ANALYSIS METHODS

3.1 OPERATIONS ANALYSIS MODEL

The primary analysis tool employed in the study is a proprietary operations analysis model that represents the operation of aircraft in aerial application missions. The basic computer program originally developed by Kenneth Razak (reference 1) was greatly expanded under Lockheed's independent development program to provide a more detailed treatment of aircraft and dispersal system performance. The model simulates the operation of any defined dispersal aircraft through any specified application mission and compiles various measures of mission performance, mission productivity, and mission cost. Figure 2 is a generalized diagram of the model.

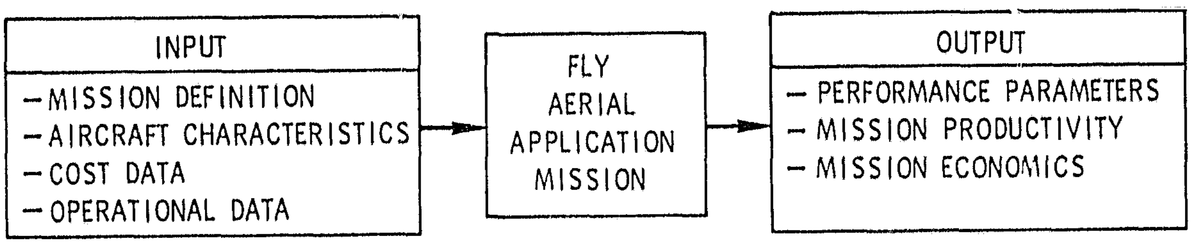


Figure 2. Operations Analysis Model

Several types of input data are inserted into the model to define a particular operation. Mission data include ferry distance to loading points and fields, number of fields to be treated from each load point, field size, material application rate, material density, and other elements. Aircraft data include various parameters defining aircraft characteristics such as zero payload weight, payload capability, lift and drag characteristics, thrust and speed characteristics, and dispersal system performance characteristics. The methods used to develop aircraft data are discussed in later sections.

Cost data inputs include aircraft operating costs, pilot pay factors, ground personnel pay factors, and fixed business costs. The development of these data is described in a later section. Operational data include a number of factors defining the particular operation such as number of ground personnel, time required for start-up and shut-down of operations each day, runway length at loading points, runway surface friction coefficient, takeoff obstacles, air density, and the rate at which material can be loaded into the aircraft. Runways at home base are assumed to be paved surfaces of unlimited length.

Figure 3 is a schematic representation of the basic model. Based on the input data for a particular case, the program calculates takeoff performance at home base and each load point using specified runway length and obstacle height. The takeoff subroutine will reduce payload when necessary to obtain acceptable takeoff gross weight for the particular conditions. The model then calculates minimum allowed swath speed, which is that speed necessary to retain 1.2 times stall speed after achieving a specified zoom height at the end of the swath. The zoom height used in the present study is 100 feet (30 m).

The program then goes through a series of trade-off routines to establish optimum swath speed and swath width values. These trade-offs involve the use of available power for the combined functions of material dispersal and aircraft flight.

The initial swath speed value is calculated to correspond to the maximum possible swath width. The maximum swath width allowed in the present study is 1.5 times aircraft wing span, which is representative of state-of-the-art capability in current liquid-dispersal operations. If the aircraft cannot achieve the minimum required speed at the 1.5 swath factor, swath width is reduced as necessary to allow additional power for aircraft flight at the minimum required speed.

The program then performs an optimization routine to determine if productivity would be increased by trading swath width for increased swath speed. The program selects the width/speed combination that produces the

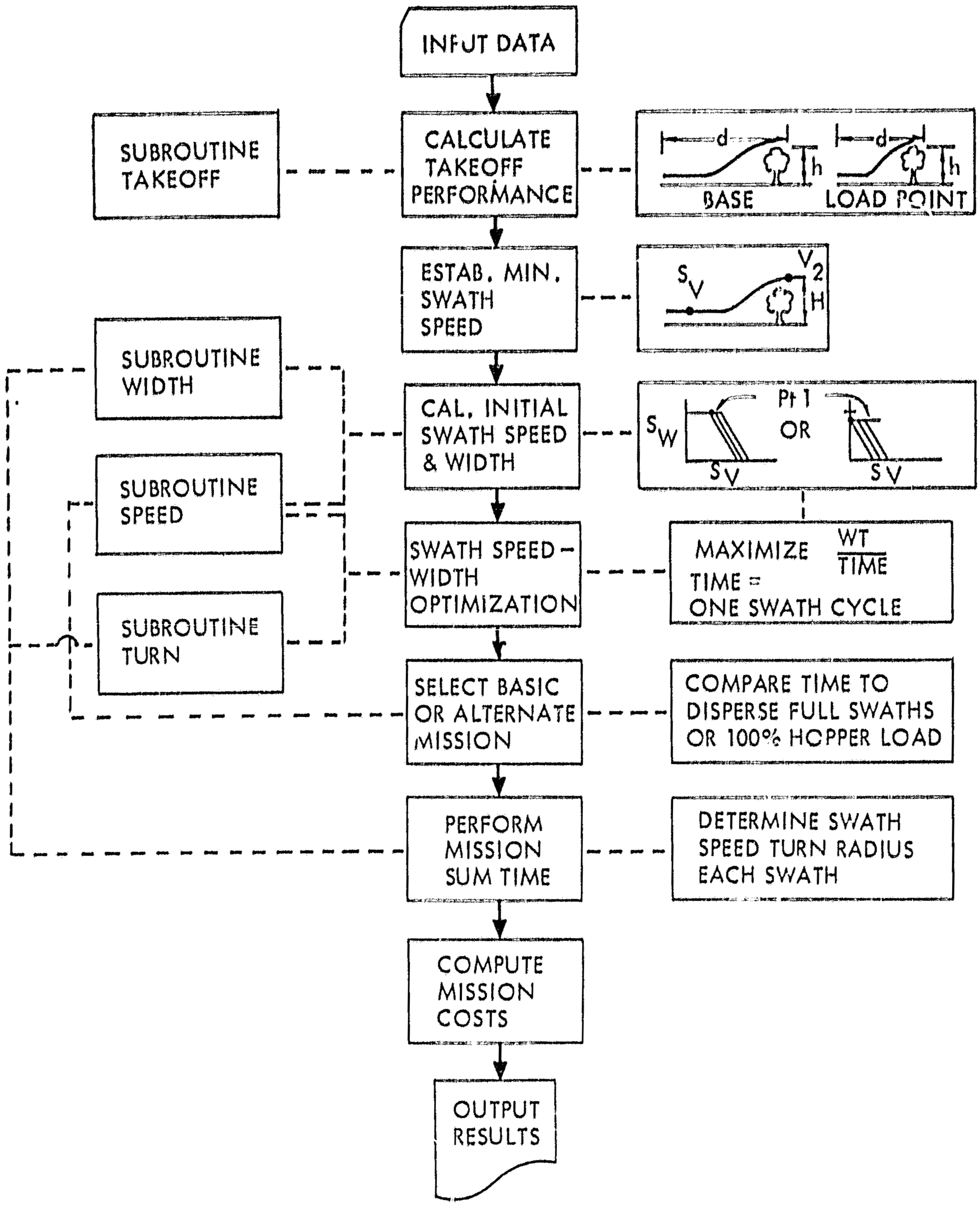


Figure 3. Operations Analysis Model Schematic

maximum weight of material dispersed per unit of time. In no case in the present study was reduced swath width at higher speed selected as being more productive, indicating that swath width has greater effect on productivity than swath speed over the range of parameters studied.

The next trade-off is maximum swath width versus emptying the hopper at the end of a completed swath. The basic mission mode is to fly at maximum swath width. However, the program calculates a reduced swath width that will allow the hopper to empty precisely at the end of a swath run for the particular field length. If this method of operation gives greater productivity, the aircraft is flown in that alternate mission mode. If maximum swath width is selected, the aircraft must deadhead back to the load point with material remaining in the hopper at the end of the last complete swath. The alternate mission mode is selected by the program in cases where material deadheading is high because aircraft payload does not match well with the field length for the specified application rate.

When these optimizations are completed, the program flies the aircraft through the mission. Ground crews and equipment are dispatched to the loading site. The aircraft ferries to the first field and begins swath runs, with a standardized procedural turn at the end of each swath. The turn subroutine calculates turn time and g load factor based on aircraft weight, drag polar, and speed/thrust values. The program tracks aircraft gross weight as material is dispersed, and swath speed is increased accordingly as the material load decreases. The aircraft returns to the load point for reloading when empty.

This process continues from sortie to sortie, field to field, and load point to load point. Ground crews and equipment are moved to the next load point when applicable. At the end of a 10-hour work day the aircraft and ground crews return to home base and shut down the operation. Operation begins the next day and continues through as many daily cycles as necessary to complete all fields specified in the mission. During the simulation, the program computes flying time in each segment, takeoff/land/taxi time, aircraft loading time, total elapsed time, amount of material dispersed, area treated, and other mission performance elements. The program also computes the cost of performing the mission.

A number of different outputs are provided, including performance parameters such as takeoff distance, takeoff payload, ferry speed, swath speed, turn time, and dispersal power. The primary mission effectiveness outputs are: (1) area treated per elapsed hour, which is the measure of mission productivity used in the study; and (2) cost per acre treated, which is the measure of mission economics used in the study. Figure 4 shows a sample output sheet from the operations analysis model.

Several different versions of the computer program have been developed to provide various capabilities for particular analyses. These versions vary in certain respects from the basic program described above. Capabilities of the complete set of programs are reflected in the data presented subsequently in this report.

3.2 WEIGHT ANALYSIS

Aircraft weight estimates throughout the study were based upon weight equations developed statistically from weight data for a large number of general aviation aircraft ranging from 2000 to 30,000 pounds (907 to 13,608 kg) design gross weight, including a number of existing agricultural aircraft. The weight estimation equations were developed under Lockheed's independent development program.

Weight estimation was accomplished in two phases. The initial candidate aircraft parametric study was conducted using operating weight empty (OWE) values derived from a statistically developed OWE equation. Weight estimates made subsequent to selection of the baseline aircraft were performed with more detailed weight prediction equations for each major airframe group, including wing, empennage, fuselage, landing gear, propulsion system, aircraft systems, and dispersal systems.

```
 AERIAL APPLICATION OPERATIONS ANALYSIS
 PROGRAM AGPR4, LIQUID DISP, FLAPS ON T.O. AND TURN
BADD DATA
 MISSION NO.   NO. LOAD POINTS   NO. FIELDS   AREA     APPL. RATE
     1              1.              6.        160.        50.

 AIRCRAFT DATA

  A I R P L A N E      GROSS WT.   PAYLOAD   WING AREA  MATL.DENSITY  WINGSPAN  LIFT COEF.    RHO    TAKEOFF H  SWA.FACT

   1  AG AIRPLANE A      7600.      3200.      380.0       60.0        55.1       1.54      .002377    50.        1.50
 TAKEOFF DISTANCE AT BASE=    1425.6 FEET   FERRY SPEED=     128.2 KTS
 TAKEOFF DISTANCE AT LOADPOINT=    1522.5 FEET   PAYLOAD=    3200.0 POUNDS   FIELD LENGTH=    4200.0FEET
 SWW= 81.2   SWL=  2640.0   WTSW=  246.2   ACRSW=    4.9   MIN SWV(KTS)=125.1   PUMP HP=  25.8   MIN G TURN= 1.86
 ITRK= 2   JTRK= 1   MAX G TURN=     3.221   MIN TURN TIME=  12.0   MAX TURN TIME=  23.9
 MAX PUMP FLOW= 147.1GAL/MIN

 APPLICATION PERFORMANCE

 *AIRPLANE * MAT.APPLIED * MAT.BEASHD * ACRES COV. * FLYING TIME* FERRY TIME * ELAP.TIME   * AREA/FL.HR. * AREA/ELAP.HR*

     1          48738.        2462.        974.8        4.48          2.35          8.28         217.8          117.7

 COST DATA (DOLLARS)
 * AIRPLANE * FIXED COSTS  * PILOTS  PAY  * GND PERSONNEL * A/C OPERATION *  TOTAL COST  * COST/ELAP.HR *  COST/ACRE   *

     1         110.29        274.34         91.13          438.70           914.45         110.38            .94

BOVRS 00     FPOF 0      FFUF 0      ERMD 0
TASK UNITS: 0      PGM SIZE:  11776
```

Figure 4. Analysis Model Output Sheet

3.2.1 Airframe Groups

The group weight prediction equations were derived using standard Lockheed computerized regression analysis techniques employing curve fitting routines (references 2 and 3). These techniques include the selection of applicable group component variables, arranging these variables as appropriate consistent with historically confirmed relationships within each group, and determining the coefficients and exponents which produce the most accurate correlation with available data. Examples of the correlation achieved are presented for the major weight groups.

Wing weight is based upon wing geometry, design gross weight, design load factor, and wing relief weight. Coefficients were developed for number and location of engines, type and location of landing gear, external wing bracing, and agricultural dispersal system structural provisions. The equation provides total wing weight for conventional aluminum construction consisting of primary and secondary structure. The correlation with existing wing weights achieved by the derived equation is shown in Figure 5.

An alternate equation for biplane wings was derived using wing loading as the controlling variable, with separate coefficients for fabric and aluminum cover skins.

Empennage weight prediction is based upon geometry, design dive speed and design gross weight. Coefficients were determined for conventional, "T" tail and externally braced configurations. Correlation with existing empennage weights is shown in Figure 6.

Fuselage weight is based upon geometry, design landing weight, ultimate load factor and limit dive speed. The major geometric factor in this equation is the "wetted" or skin area. Coefficients were determined for conventional monocoque aluminum construction, steel tube construction, and alternate landing gear and power plant locations. Correlation with existing weight data is shown in Figure 7.

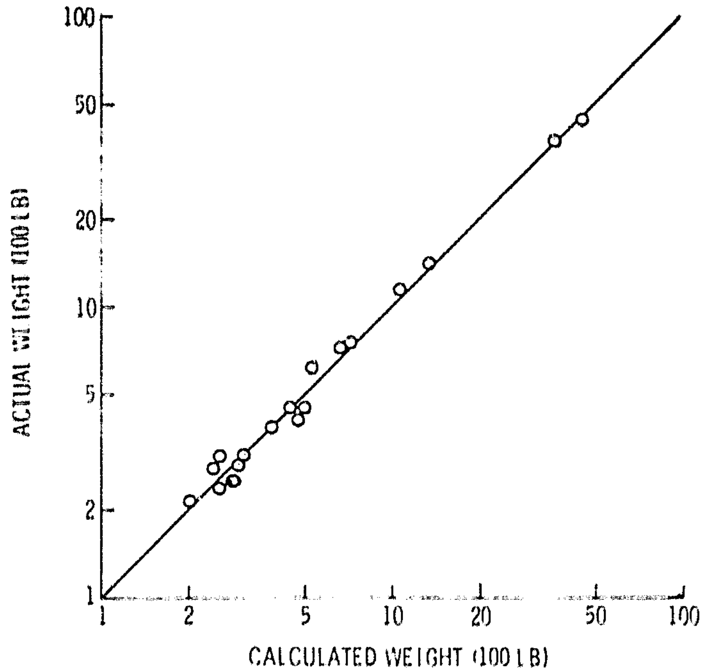


Figure 5. Wing Weight Correlation

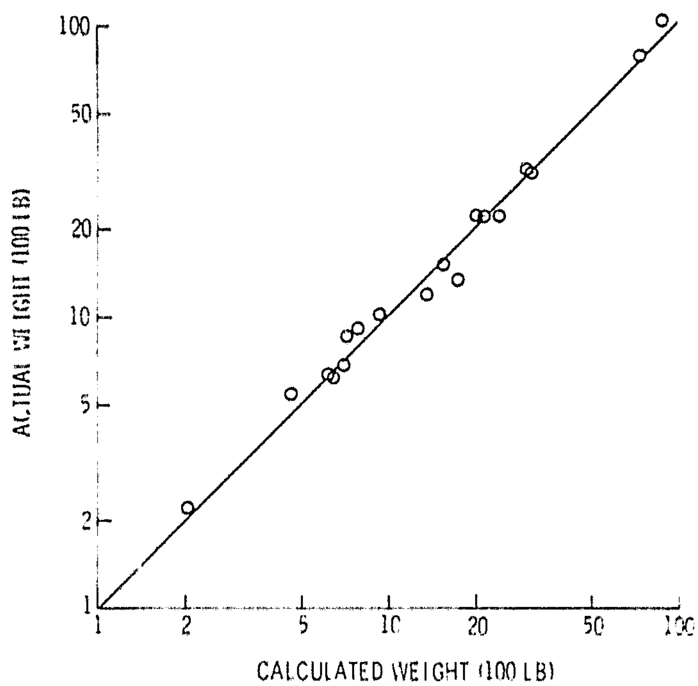


Figure 6. Empennage Group Weight Correlation

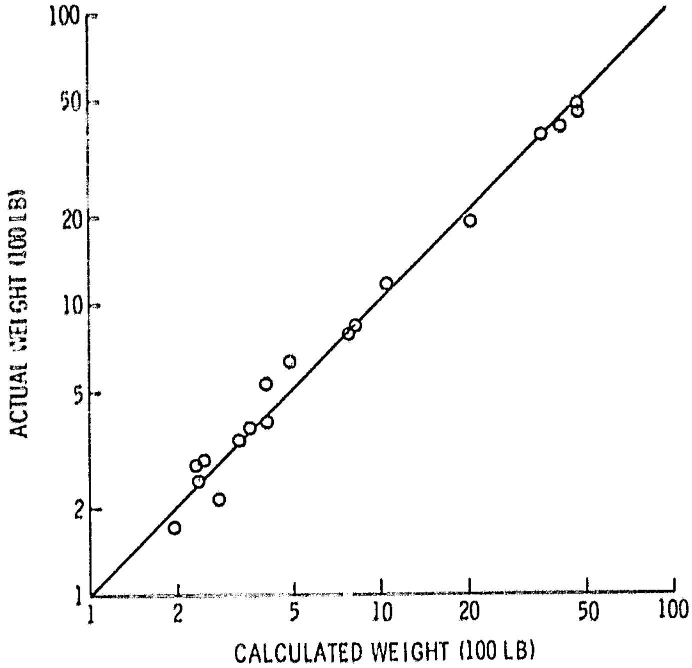


Figure 7. Fuselage Weight Correlation

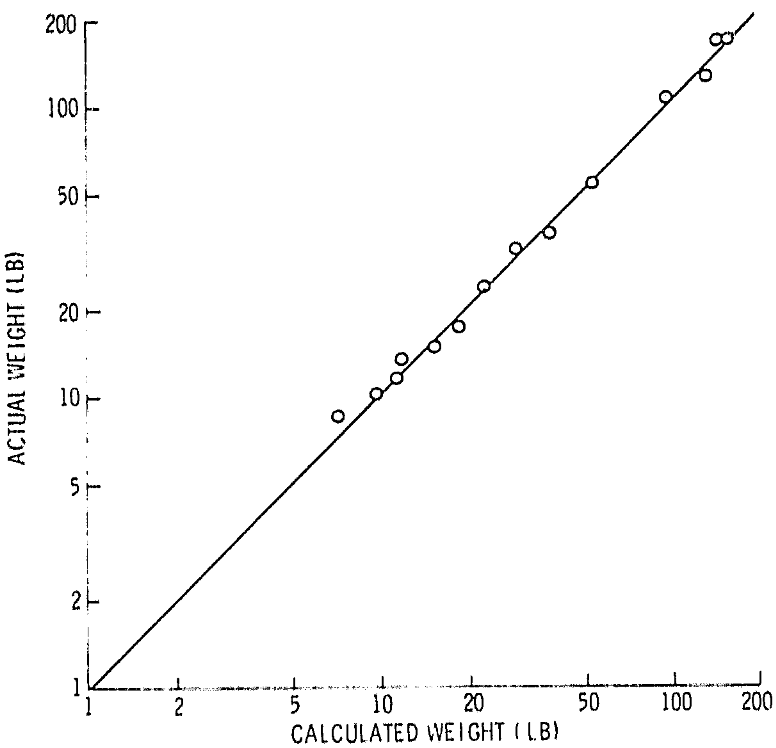


Figure 8. Landing Gear Weight Correlation

Landing gear weight prediction is based upon design landing weight, with derived coefficients for tail wheel type, tricycle, fuselage mounted, and wing mounted gear, with and without rough field capability and high flotation. Calculated versus actual gear weights are shown in Figure 8.

Propulsion Group weight is predicted by two separate equations. Propeller weight is based upon diameter. number of blades and engine shaft horsepower. The propulsion group is then determined using the propeller weight and the dry engine weight with installation coeffients for either piston or turbo-prop engines. The engine weight used can be either specification value or that derived from generalized curves. The propulsion group weight includes systems, controls, fuel system and tanks, lubrication, exhaust, tailpipes, engine mounts and nacelle/cowling. Correlation with actual weights is presented in Figure 9.

Aircraft systems weights are predicted for the simplified aircraft systems required for normal agricultural operation. The estimates are based upon aircraft gross weight and include surface controls, electrical system, austere furnishings and equipment for one pilot, minimum heating and ventilation, minimum hydraulics, avionics and instrumentation.

The weight equation developed for the agricultural dispersal systems is a statistical curve fit based upon reported system weights from availble agricultural aircraft and equipment selection from various manufacturers for typical installations, with extrapolation for higher gross weight aircraft. The weights predicted by the equation are in close agreement with system weights in available reports. Hopper weights are included in the weight estimate and are a function of hopper load and aircraft design gross weight. Hopper weight is then determined to be a percentage of total dispersal system weight.

3.2.2 Aircraft Empty Weight

The summarization of these group weight predictions provides the weight empty for the selected aircraft with the following accuracy:

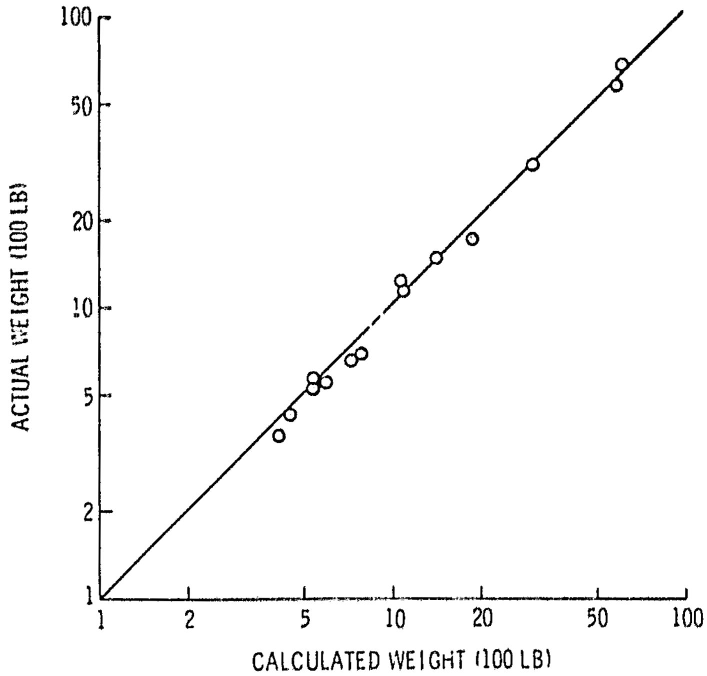


Figure 9. Propulsion System Weight Correlation

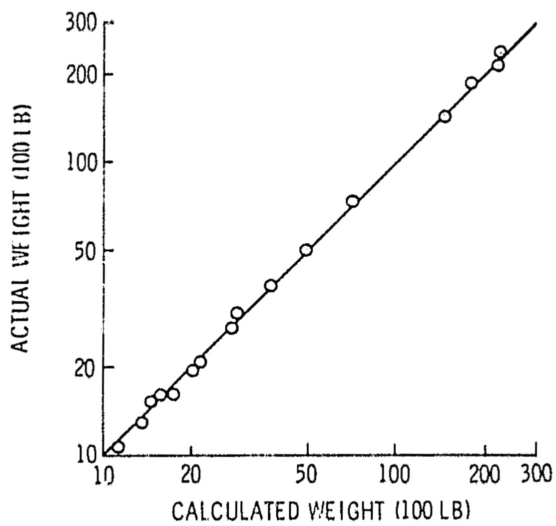


Figure 10. Aircraft Empty Weight Correlation

S = Standard Deviation = .041

80% confidence level for S is .034 to .054

90% confidence level for S is .032 to .058

Correlation of aircraft empty weights computed by the established methods with actual aircraft empty weights is illustrated in Figure 10.

3.2.3 Aircraft Gross Weight

The agricultural aircraft designs analyzed during this study were developed under groundrules established to recognize two different gross weights: a design gross weight, and a restricted gross weight.

The design gross weight is the weight established for structural design, and corresponds to the maximum gross weight at which the aircraft would be certificated under the normal catagory of FAR Part 23. The structural weight of the aircraft reflects a design limit maneuver load factor of:

$$n_1 = 2.1 + \frac{24000}{W + 10{,}000}$$

to a maximum of 3.8, where

W = design gross weight in pounds.

The restricted gross weight is the takeoff gross weight at which all mission analysis is conducted. Restricted gross weight is established by applying the maximum suggested overload weight factor presented in Section 7.1 of Appendix A of CAM 8 (reference 4) to the design gross weight. The CAM 8 weight factor is determined as a function of the airplane design limit load factor. Airplane design limit load factor and the CAM 8 overload weight factor are plotted as a function of FAR Part 23 design gross weight in Figure 11.

The mission payload used in all operations analyses is established by subtracting the airplane Zero Payload Weight from the restricted gross weight. The aircraft Zero Payload Weight is the sum of the aircraft empty

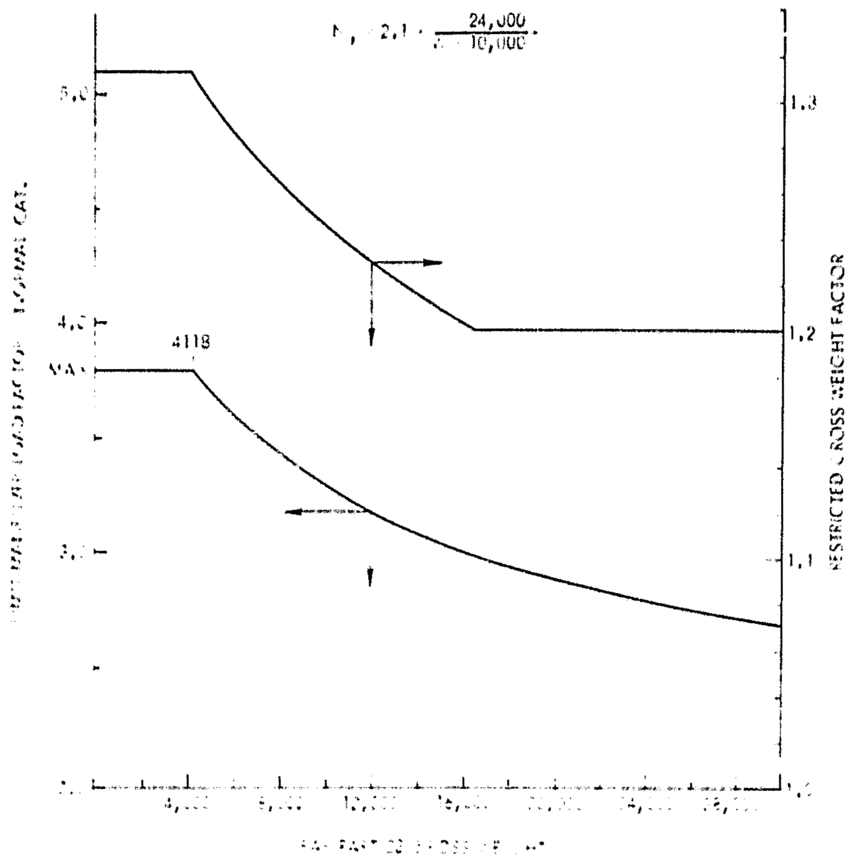


Figure 11. FAR 23 and CAM 8 Factors

weight, a pilot weight of 170 pounds (77 kg) and fuel weight adequate for approximately three hours endurance at economy cruise power.

3.3 AERODYNAMIC ANALYSIS

The determination of the complete drag for each configuration considered in the study resulted in a drag polar build-up comprised of zero-lift and induced drag. The zero-lift drag for each component was established by determining the skin friction drag coefficient at the appropriate flight Reynolds number plus additional drag allowances for interference and slip-stream, surface roughness and trim. Special attention was given to the assessment of drag of the fixed landing gear and the large, high visibility canopies associated with agricultural aircraft (reference 5).

The induced drag of monoplanes was determined from empirical wing efficiency factor (e) data (reference 6) for a variety of straight wing aircraft. The induced drag characteristics of biplanes were determined by methods accounting for the span, chord and gap between upper and lower wings (reference 7). This resulted in an equivalent monoplane aspect ratio for the biplane with both wings developing the same wing loading. For the case where the lower wing is unloaded, the induced drag then became a function of the upper wing aspect ratio alone.

The lift and drag contribution of simple, single slotted, 25% chord trailing edge flaps was also assessed (reference 8). These devices provide no chord extension with deflection. The maximum deflection studied was 20 degrees, primarily to improve take-off performance.

The maximum lift coefficient developed on the unflapped and flapped wings was evaluated utilizing the methods of reference 9. The basic airfoil sections were chosen with good high-lift characterstics, and the additional contribution of trailing edge flaps and slipstream (on propeller powered configurations) was also included. The slipstream effect assessment was based on reference 10 and standard Lockheed aerodynamics handbook data.

3.4 PROPULSION SYSTEM PERFORMANCE

The performance of the propulsion systems used in the agricultural aircraft study was derived from candidate engine data representing engines that are anticipated to be certificated and in production in the mid-1980's. These data were acquired directly from the engine manufacturers at the outset of the study, and they represent the most current information available on small commercial engines that are appropriate for consideration for agricultural aircraft in the time period.

Each manufacturer states that the candidate engines will be manufactured to satisfy the EPA emission standards in effect at the time. In an official publication in April 1978, the Environmental Protection Agency proposed to drop all engine emission standards for general aviation engines of 6000 pounds thrust (or equivalent horsepower) or less. This policy is expected to alleviate any impact of emission controls on agricultural aircraft design and operation in the mid-1980 period.

FAR Part 21, subsections 21.183(e)(2) and 21.185(d) specifically exclude aircraft designed for "agricultural aircraft operations" from compliance with operational noise requirements specified in FAR Part 36. Because of this, noise constraints were not considered in the estimation of propulsion system performance for the agricultural aircraft study.

3.4.1 Candidate Powerplants

Powerplants considered appropriate for investigation as agricultural aircraft powerplants include horizontally opposed reciprocating air cooled engines, turboprop and turboshaft engines, turbofan engines, and ducted fan propulsors. A recent development of a converted water cooled V-8 automobile engine may also be appropriate for future consideration, pending progress toward FAA certification as an aircraft engine. Radial reciprocating aircraft engines were not considered in the study. No engines of this type of adequate horsepower are currently in production in the western nations, and the former manufacturers contacted indicated no intention to restart manufacturing these engines.

The candidate powerplants for which data were acquired are listed in Table I. In addition to performance and weight data, original equipment manufacturer (OEM) prices were acquired for the candidate powerplants. Engine performance data were used in conjunction with the propeller performance estimation method (reference 11) to establish generalized installed thrust data. Engine weight data were used to establish generalized weight versus horsepower relationships. The OEM prices were used to establish generalized engine cost versus horsepower relationships for determining aircraft operating costs, as discussed in Section 3.6.

3.4.2 Installed Thrust

Two methods of estimating aircraft performance were considered: use specific engine data from the list of candidate engines; or establish generalized powerplant performance data from the candidate engine data to represent typical engines anticipated to be available in the time period. The latter approach was chosen.

Propeller performance was estimated using the method outlined in reference 11. Several propeller design parameters including diameter, activity factor, integrated section lift coefficient, and RPM were investigated to establish the influence of these parameters on thrust lapse rate with speed in the horsepower range of interest. This investigation resulted in basing the propulsion system performance on propellers having an activity factor of 125, an integrated section lift coefficient of 0.5, and diameters based on the relationship,

$$D = .3482 \sqrt{HP}$$

where D = diameter in feet, and H.P. = takeoff horsepower. These parameters appear to provide a good compromise between takeoff thrust and thrust during swath runs at speeds between 100 and 200 knots.

Several candidate engines ranging from 290 to 1175 shaft horsepower (216 to 876 kw) were used to determine installed thrust as a function of airspeed from 0 to 200 knots. These data were crossplotted to provide the gener-

TABLE I - CANDIDATE ENGINES

TURBINE	Performance (SL, ISA, Static) SHP or Thrust		Weight (lb)	
Turboprop (1)				
Avco Lycoming LTP101-600	600	(447 kw)	320	(145 kg)
Avco Lycoming LTP101-700	671	(500 kw)	320	(145 kg)
Garrett AiResearch TPE331-3U-303G	840	(626 kw)	340	(154 kg)
Detroit Diesel Allison 250-B17B	400	(298 kw)	195	(88 kg)
Pratt & Whitney Canada PT6A-45	1174	(875 kw)	423	(192 kg)
Pratt & Whitney Canada PT6A-34	750	(559 kw)	311	(141 kg)
Turboshaft				
Avco Lycoming LTS101/650 C-2	675	(503 kw)	232	(105 kg)
Garrett AiResearch TSE331	800	(597 kw)	355	(161 kg)
General Electric CT7	1536	(1145 kw)	430	(195 kg)
Detroit Diesel Allison 250-C20	650	(485 kw)	235	(107 kg)
Pratt & Whitney Canada PT6B-34	900	(671 kw)	293	(133 kg)
Turbofan				
Pratt & Whitney Canada JT15D-4	2500	(11,120N)	557	(253 kg)
Williams Research F107	600	(2669N)	130	(59 kg)
RECIPROCATING (1)				
Horizontally opposed				
Avco Lycoming IO 540 Family	300	(424 kw)	425	(193 kg)
Avco Lycoming IO-720	400	(298 kw)	600	(272 kg)
Teledyne Continental IO 520 family	300	(224 kw)	450	(204 kg)

(1) Propeller manufacturers: Hamilton-Standard, Hartzel, McCauley, Dowty-Rotol

alized performance data defining thrust and speed as a function of installed shaft horsepower shown in Figure 12.

3.4.3 Propulsion System Weight

Engine dry weight data supplied for the candidate engines were employed to establish the generalized turboprop engine weight to horsepower relationship shown in Figure 13. Propeller weights established statistically vary primarily with horsepower and diameter. Combining the propeller diameter and statistical weight relationships provides the propeller weights estimation equation:

$$W_p = .2515\ (SHP)^{1.04}$$

where W_p is propeller weight and SHP is installed shaft horsepower.

3.5 DISPERSAL SYSTEM PERFORMANCE

Mission performance is determined for two dispersal cases, liquid material and dry material. The material characteristics, dispersal techniques, and effects on airplane performance of these cases are totally different; consequently, two different versions of the operations analysis model were developed. The methods used by these models to determine mission productivity and costs are identical, but the methods of accounting for the drag and power extraction of the dispersal systems on takeoff, ferry, swath and turn performance are unique to the material being dispersed. The methods used were developed from both analytical and emperical approaches.

3.5.1 Liquid Dispersal Systems

The penalties imposed on airplane performance by liquid dispersal systems include the aerodynamic drag of externally mounted components, the increase in drag or loss of thrust to the power extraction of the liquid pumping system, and the loss of payload to the weight of the liquid dispersal system. Dispersal system weight is discussed in Section 3.2.

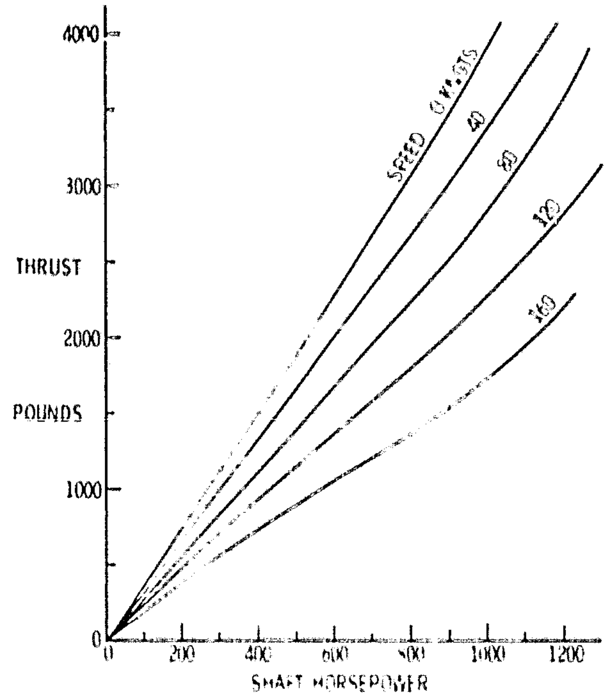


Figure 12. Propulsion System Performance

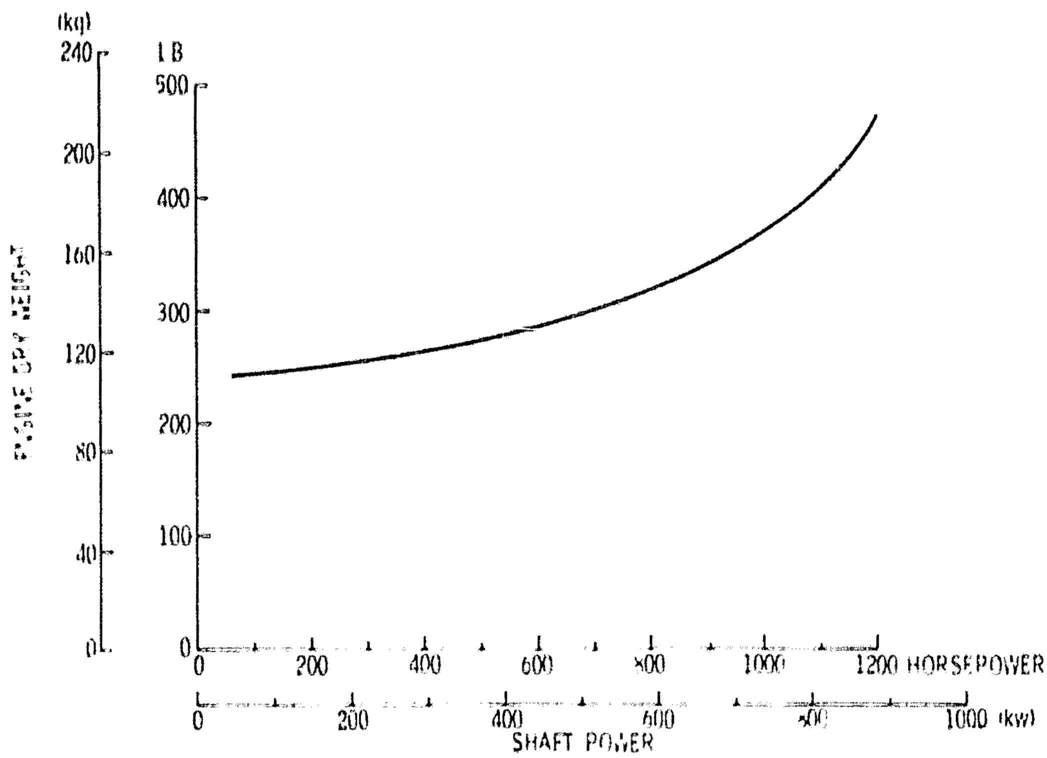


Figure 13. Generalized Turboprop Engine Weight

3.5.1.1 External Drag - The number, type, and arrangement of external components used on ag airplane liquid dispersal systems vary widely, depending upon the manufacturer and individual operator. For this study it was necessary to establish a standard method of estimating the drag of a typical system configuration. This was done by accounting for the system drag from three sources: (1) pump and pump-boom-hopper interconnecting plumbing; (2) boom, boom supports and interference; and (3) nozzles.

Dimensional data for system components similar to those used on aircraft for which flight test data are available (references 10, 12, 13, and 14) were obtained from equipment catalogs and specifications. Drag estimates were made based on estimated drag coefficients, and the total drag was compared to the measured drag reported in the references. This procedure was iterated until it appeared that a reasonable correlation was achieved.

The aerodynamic drag coefficient of the pump and external plumbing, including interference, was established to be:

$$C_{D_P} = \frac{.652}{S_W}$$

where S_W = referenced wing area in square feet.

The estimated boom, boom supports and interference drag coefficient is:

$$C_{D_B} = \frac{.15}{S_W} \times b_W$$

where bw = wing span in feet,

and the drag coefficient of the nozzles is:

$$C_{D_N} = \frac{.025}{S_W} \times b_W$$

The drag of the external components is computed and added to the total airplane drag for all phases of the mission.

3.5.1.2 Pumping Power - The hydraulic horsepower represented by the energy lost to liquid material mass flow through the pressure drop of the nozzles is power extracted from the energy potential of the system. Energy potential can be in the form of storage devices such as electrical batteries or pressure tanks, but in all but very unusual cases the energy potential is represented by the fuel consumed by the main propulsion engine. Power extraction can be direct from the propulsion engine as shaft power or as high pressure bleed air from the engine compressor, or it can be indirectly extracted from the freestream energy, which is generated by the engine-driven propulsion system.

Regardless of the manner in which the power is extracted, some energy is lost to inefficiencies in the power conversion mechanism. The best system for transferring the required energy into the liquid material being dispensed will be a system that achieves best mission performance, considering not only conversion efficiency, but also the weight penalty, acquisition and operating costs, reliability, maintainability and all other factors effecting total mission productivity and cost.

The performance penalty imposed on the liquid dispersal mission by the energy transfer into the liquid material is accounted for as a drag term added directly to the basic airplane drag. This additive pumping drag is derived to be:

$$D_P = \frac{.00331 \times PSI \times RPA \times B \times SF}{EP \times ED \times DM}$$

where D_P = drag due to pumping, in pounds;

PSI = liquid system operating pressure, in pounds per square inch;

RPA = material application rate in pounds per acre;

B = airplane wing span in feet;

SF = swath width factor relative to wing span;

EP = effeciency of liquid pump;

ED = efficiency of the mechanism driving the pump; and

DM = density of the liquid material being pumped.

It should be noted that swath speed does not appear in this equation. The analysis shows that for a given swath width, established by wingspan and swath factor, the horsepower required to provide a material flow rate adequate to maintain a constant application rate varies directly with swath speed. Thus, the drag equivalent of this horsepower is a constant value, independent of speed.

3.5.2 Dry Material Dispersal Systems

The penalty imposed on airplane performance by dry material dispersal systems is primarily aerodynamic drag created by airflow both around and through the spreader located below the hopper exit. At the time of this study no wind tunnel test data and very little flight test data existed which would permit the estimation of spreader drag or provide a relationship between swath width, material application rate, and system drag. Available data consisted of that presented in references 12 through 17. In order to provide a technique for estimating mission performance on dry dispersal missions, these data were used to establish one expression defining swath width as a function of application rate and a second expression defining the additive drag of the spreader as a function of the airplane lift coefficient.

The data presented in the referenced reports permitted estimation of the swath width and application rate by inspection of the swath spread cross-sections. An example of these data from reference 17 is presented in Figure 14. Measured deposition rate is plotted as a function of distance to either side of the aircraft centerline track on the ground. Swath width limits are established at the outermost points of the cross-section at which the overlap of an identical, adjacent swath would produce the most even coverage of material on the field. Between these limits the variations in deposition rate are averaged to establish the effective application rate for the effective swath width.

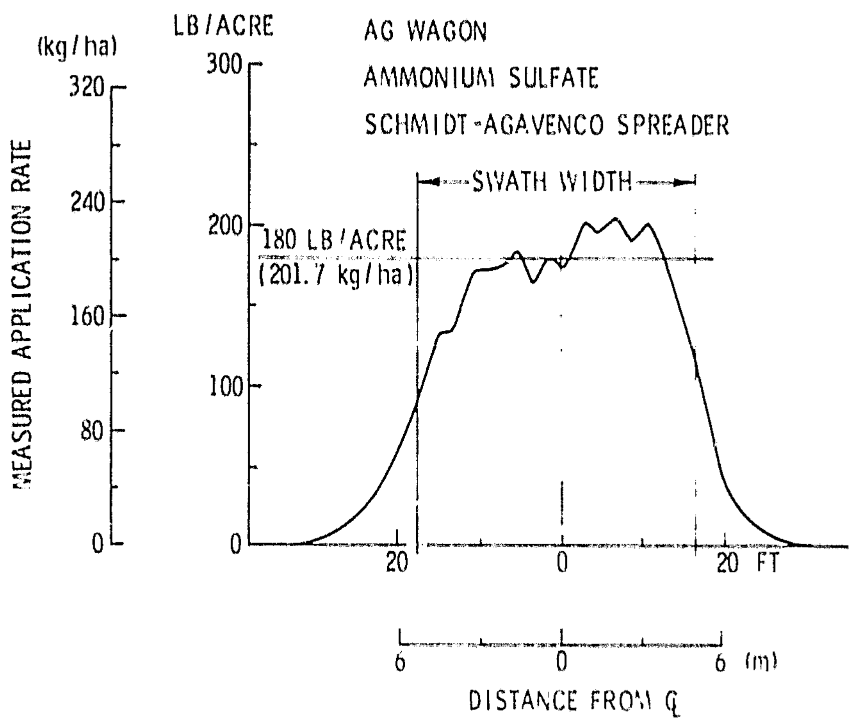


Figure 14. Measured Swath Cross Section

This procedure was applied to all available swath cross-section data and the results plotted as shown in Figure 15. For information, the numbered data points in the figure represent cases in which measurements were made of equivalent horsepower consumed by spreader drag. A curve was fit through the data points representing conventional dry material spreaders. The equation of this curve is:

$$SW = \frac{315.}{(RPA)^{.4}}$$

where SW = swath width in feet,

RPA = application rate in pounds per acre.

The developed expression provides a relationship between swath width and application rate, but does not establish the drag penalty imposed on the aircraft. The flight test data of references 10, 12, and 13 provide incremental power required to overcome the additive drag of the dry spreaders. These data were reduced to power-on drag coefficients over the range of aircraft lift coefficients provided by the airspeed ranges tested. Tests were conducted on each aircraft at high and low gross weights. The relationship of the spreader drag coefficients and aircraft lift coefficients of the test aircraft are presented in Figure 16. Considerable variation in this relationship is shown between different aircraft and for a given aircraft at different weights. In order to establish a lift-drag relationship that can be used in the operations analysis model, a line was fit to the data shown in the figure. The resulting expression for this relationship is:

$$C_D = 0.0596 \times C_L + 0.012$$

As is apparent, the drag of the dry spreader is independent of material application rate. Dry material mission performance is computed using spreader drag established as a function of the airplane lift coefficient.

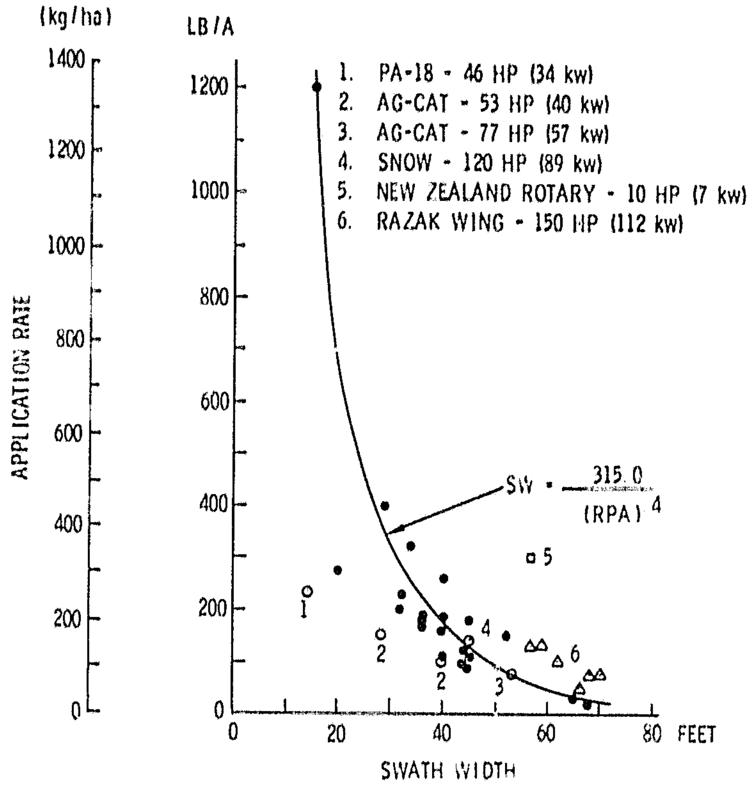


Figure 15. Dry Material Spreader Tests

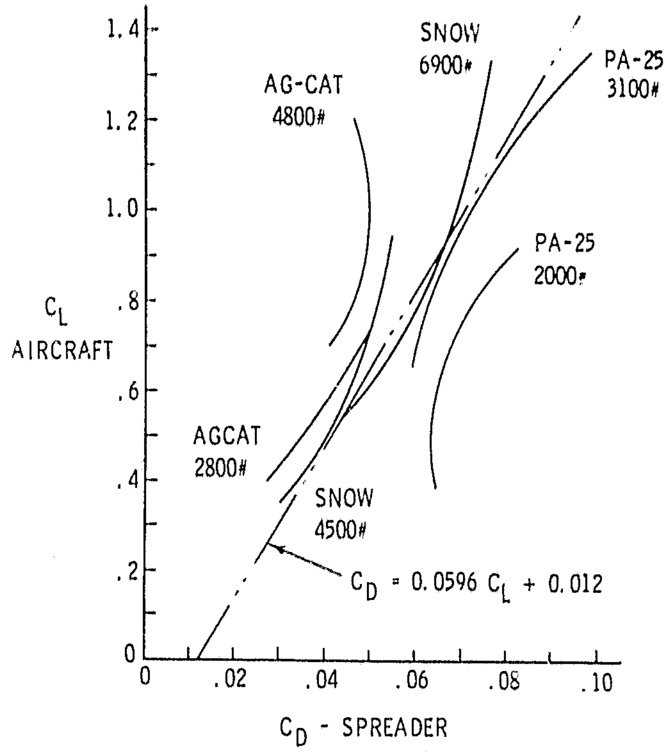


Figure 16. Dry Spreader Drag

3.6 COST ESTIMATING METHODS

3.6.1 Analysis Model Input Data

A number of different types of cost estimates are required to develop the input data for the operations analysis model. The specific input values are aircraft operating cost per flight hour, pilot pay factors, ground personnel pay rates, and fixed business costs. Aircraft operating cost, which is the most complex of these data elements, is discussed separately in the next section.

Within the aerial application industry, pilots are commonly paid a percentage of the income generated by the missions they fly. This income is based on fees charged for the service, and pricing policies vary with regions of the country and types of missions. In the present study, mission economics are treated strictly in terms of estimated operator costs without consideration for fees charged the customer. Pilot pay is computed in the analysis model so as to constitute 30% of the total cost of performing the mission.

Ground personnel pay rates used in the model for the present study are $2.50 per working hour for flagmen and laborers and $3.50 per working hour for driver/loader operator. Two flagmen, one laborer, and one driver/loader operator are assumed in all cases.

Fixed business cost represents overhead type costs such as office expenses which vary with the size of the business rather than the type of mission or type of aircraft used. These costs are represented in the present study by an arbitrary lump-sum amount of $2000 per month, which is then prorated to the mission based on the elapsed hours required to perform the mission. An additional prorated cost was added to account for purchase of loading equipment needed to satisfy the material loading rates used in the model. Loader capacity was matched to the hopper capacity of each aircraft configuration, with costs based on currently available state-of-the-art loading equipment purchased new.

All cost values used in the study are stated in 1977 dollars.

3.6.2 Aircraft Operating Cost

The proprietary methods used to estimate aircraft operating costs were developed in Lockheed's independent development program. Methods and data were derived from a number of sources, including a variety of published sources as well as contacts with aerial application operators and fixed-base support operators.

Primary source documents for the operating cost model were two general aviation cost studies sponsored by the Federal Aviation Administration (references 18 and 19) and a previous general aviation technology study performed by Lockheed for NASA Ames Research Center (reference 20). The methods and data contained in these documents were updated and modified extensively to apply specifically to agricultural aircraft.

Cost equations and estimating factors were developed for each operating cost element based on the nature of the cost element and available data defining cost relationships. In each case, a generalized cost equation was formulated to relate the cost parameter to physical and/or performance characteristics of conceptual aircraft designs of the type considered in the present study. Aircraft empty weight and engine power, for example, are primary design parameters used in several of the cost equations. In several cases, the estimating equations are derived statistically by fitting regression lines to actual data points.

Engine overhaul cost is used to illustrate the technique. Current average cost per overhaul and time-between-overhaul (TBO) values were obtained for a number of different engines over a range of rated power levels. Both reciprocating and turboprop engines were included. These values were converted to the form of average cost per flight hour and plotted against engine power level. The data indicated that reciprocating and turbine engines follow the same trend relationship. A single regression line was fit to the total set of data points, and the equation of this line was used for cost estimates in the study. The primary source of data in this case was the Aircraft Price Digest (reference 21) which contains current TBO's and overhaul costs for most engines in general aviation use. Figure 17 shows the engine overhaul data and the cost estimating equation derived from the data.

The specific cost elements included in the operating costs are as follows:

Fuel and Oil	Liability Insurance
Annual Inspection	Taxes
Unscheduled Maintenance	Annualized Investment
Engine Overhaul	Miscellaneous
Hull Insurance	

Most of these categories are standard within the industry. Fuel and oil costs are based on average consumption per unit of engine power for reciprocating and turboprop engines, using $.62 per gallon ($.164/liter) for aviation gasoline and $.43 per gallon ($.114/liter) for diesel fuel. Hull insurance for the aircraft is based on current premium rate trends within the industry, with the insurance fee represented as a declining percentage of aircraft cost as the purchase price increases. Liability insurance including chemical damage coverage is treated as a flat fee of $1000 per year for each aircraft, which is representative of current cost. Taxes cover federal registration fees and weight tax based on Internal Revenue Service tax instructions. Miscellaneous costs cover a variety of minor expenses based on data in the FAA cost studies referenced earlier; this cost element is an insignificant portion of the total operating cost.

Annualized investment is not a standardized cost element in determining the operating cost of agricultural aircraft. The purpose of this element in the present study is to provide a representation of the cost of purchasing the aircraft. There are various procedures by which such costs can be represented as operating costs, including different types of depreciation procedures and/or statements of interest costs on loans. In the present study this element has been treated simply as a straight-line proration of the aircraft purchase price over a ten-year operating period. That is, 10%

of aircraft acquisition cost is counted each year as an operating cost. No interest charges are included in the basic cost model.

Aircraft operating cost input to the operations analysis model is stated in the form of cost per flight hour. A number of the cost elements actually accrue on an annual basis, however, and are not a direct function of flight hours. Costs of this nature were prorated to a flight-hour base by use of an assumed annual utilization rate of 600 flight hours per year. Sensitivity data are given in Section 7.3 to show the effect on operating costs if other utilization rates are used.

3.6.3 Aircraft Acquisition Cost

The acquisition cost estimating model is shown in simplified form in Figure 18. The basic approach is to estimate airframe labor and materials costs based on aircraft weight, engine cost based on engine rated power, and dispersal system cost based on dispersal system weight. All of these costs are estimated through statistical equations derived from actual data for current aircraft and equipment. These cost elements are totaled to give estimated aircraft manufacturing costs. Typical industry factors are then applied for various overhead and amortization elements, manufacturer's profit goal, and distributor and dealer mark-up. The resulting estimate corresponds to "factory flyaway" (FAF) price or manufacturer's suggested retail list price.

The proprietary estimating model was developed under Lockheed's independent development program using data from a variety of sources, including analysis of a wide range of general aviation aircraft as well as agricultural aircraft. The basic cost estimating concept is described in the previous Lockheed study report prepared for NASA Ames (reference 20), and a similar approach is described in an article by James N. Lew of Beech Aircraft Corporation (reference 22).

A production quantity of approximately 1000 units was assumed for the study aircraft as a basis for cost estimates. This quantity is representative of

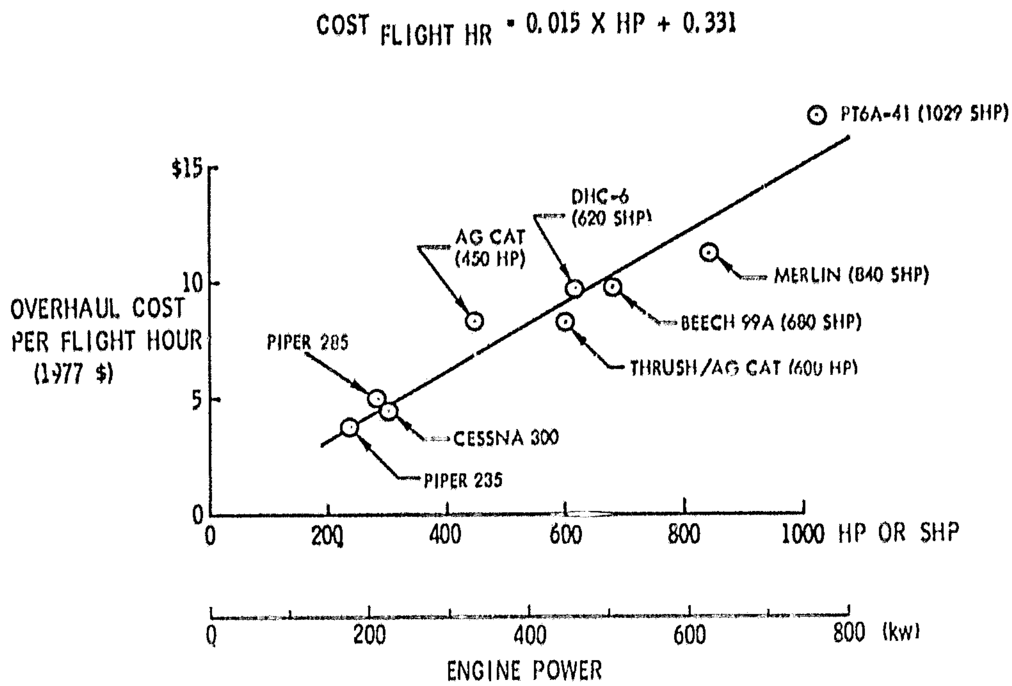


Figure 17. Engine Overhaul Cost

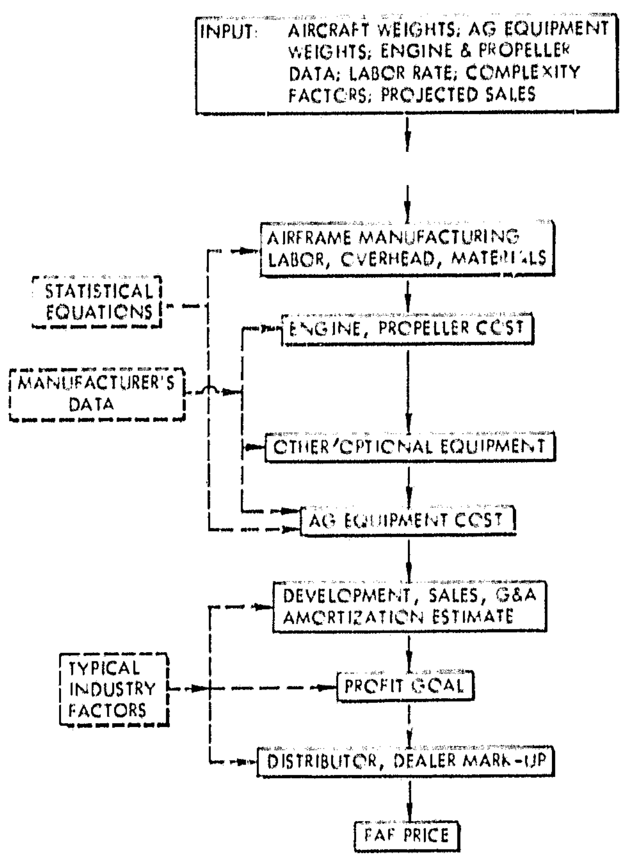


Figure 18. Acquisition Cost Estimating Model

manufacturing learning ve benefits and amortization factors reflected in the statistical data used in the estimating model.

Figure 19 illustrates the statistical technique used to develop labor and materials costs as a function of aircraft empty weight. The figure shows an estimating line fit to materials cost data points for a large number of current general aviation aircraft, including several agricultural aircraft. Figure 20 illustrates the same technique for estimating original equipment manufacturer's (OEM) cost for turboprop engines as a function of rated shaft horsepower.

Figure 21 shows cost estimates obtained from the estimating model for several current agricultural aircraft in comparison with published list prices for these aircraft. Ideally, all of the estimates should fall exactly on the line shown in the figure. In fact, a number of the estimates are higher than the list prices, and the deviation appears to increase as the price of the aircraft increases.

The comparison suggests that acquisition cost estimates developed for conceptual aircraft in the present study are excessively high, particularly for larger aircraft. This may well be the case. However, there are a number of qualifying factors, such as the degree to which amortization of development costs is reflected in current prices for aircraft developed many years ago. Several agricultural aircraft are produced by companies with no other aircraft product line, which may affect overhead and pricing procedures. The labor pay rates, overhead factors, and mark-up factors used in the estimating model are representative of the general aviation industry as a whole, and these factors may be more accurate for future agricultural aircraft than indicated for some of today's aircraft.

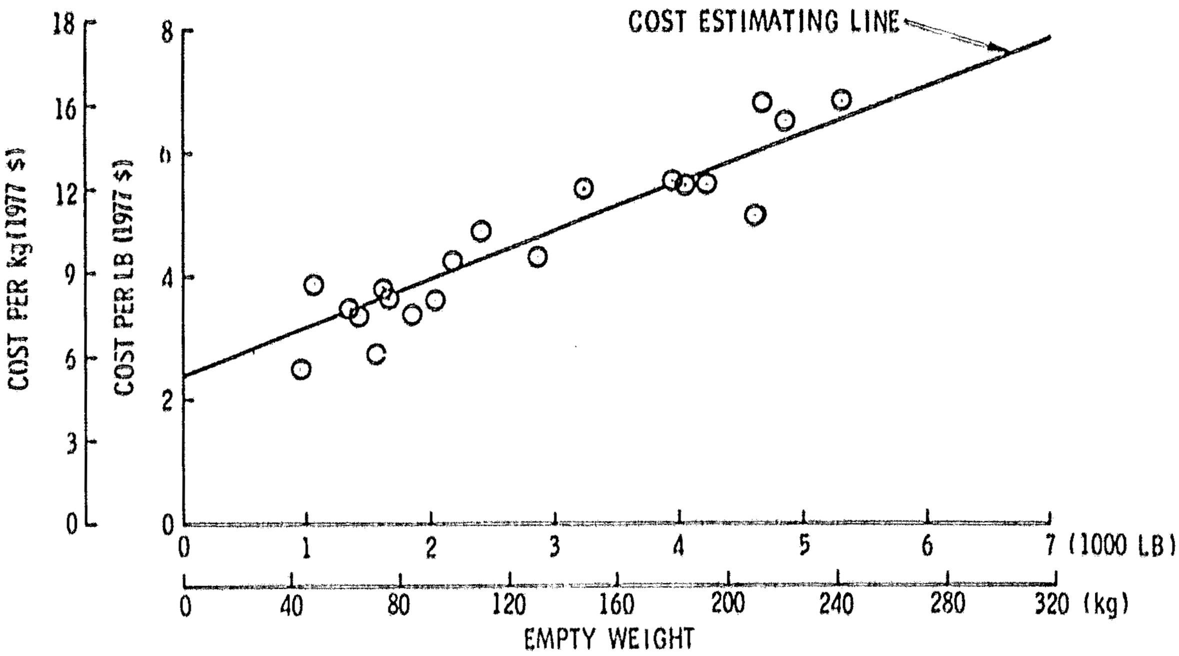


Figure 19. Airframe Materials Cost

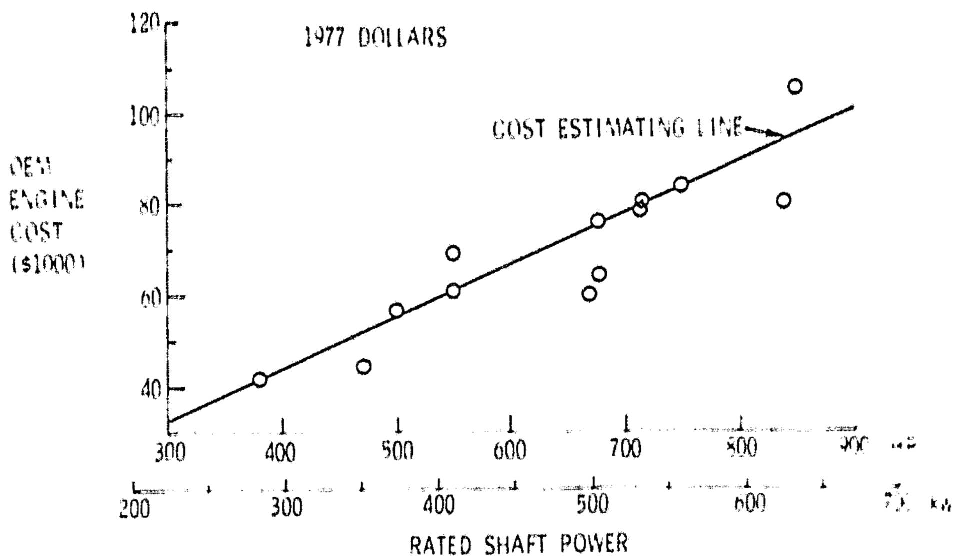


Figure 20. Turboprop Engine Cost Data

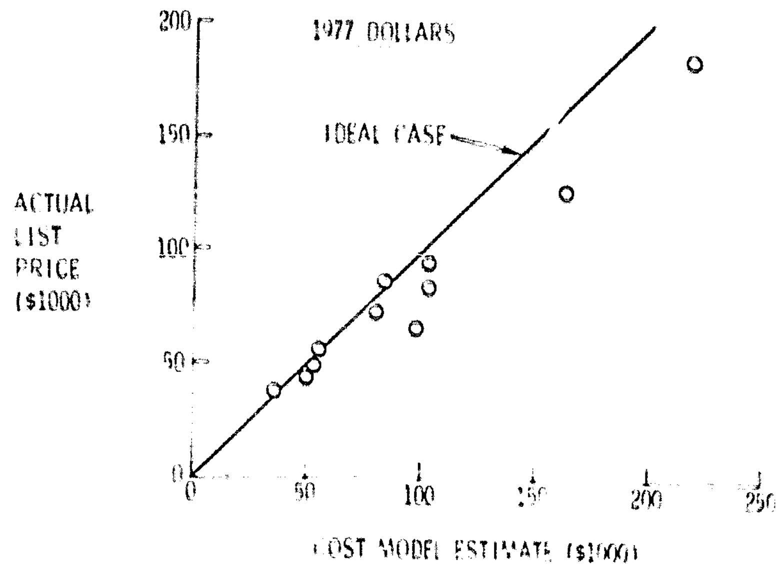


Figure 21. Cost Model Estimates vs. Actual Prices Current Agricultural Aircraft

4.0 SYSTEM CONFIGURATIONS

The work conducted under the System Configurations task addressed the development of a data base representing optimized fixed-wing aerial application systems, including aircraft, airborne dispersal subsystems, and ground operations support subsystems. The work was accomplished through an iterative process in which candidate aircraft configurations were evaluated by parametric mission analyses, baseline configurations were selected for sensitivity studies, and alternative system designs were considered in comparative evaluations. Systems appearing to offer the greatest potential for effectively performing current and future aerial application missions were selected to illustrate the system configurations.

4.1 CANDIDATE CONFIGURATIONS

The initial parametric system evaluations were conducted on nine candidate configurations encompassing the range of system parameters defined by the NASA study guidelines. The approach in establishing these candidate configurations was to represent to the extent possible current agricultural aircraft designs. This permits potential design improvements to be derived from and be evaluated relative to current state-of-the-art systems.

Certain configuration design philosophies were established at the outset and maintained throughout the study. Foremost among these is the location of the cockpit relative to the powerplant(s) and material hopper(s). The design established by Weick in the AG-1, in which the pilot is located aft of the major mass components of the aircraft (engine, hopper, wing structure) and protected by an outwardly collapsing cage structure has been tested time and time again in crash situations and has proved through pilot survival rates to be a sound and superior approach to the design of agricultural aircraft.

Pilot visibility requirements have been established to be no less than those required for Air Force fighter aircraft over-the-nose (11° downward on the centerline), with an unobstructed upper hemisphere above a waterline through the pilot's eye position. The latter assures full view of the field being treated throughout the turn at the end of each swath run.

Eight initial candidate aircraft designs were established based upon payload weights of 1000, 3000, 6500 and 10,000 pounds (454, 1361, 2848, and 4536 kg) and payload densities of both 33 and 100 pounds per cubic foot (529 and 1603 kg/cu. m.). An additional design based on a payload weight of 4500 pounds (2041 kg) and 33 lb/cu. ft. was added to more clearly establish the performance variation with aircraft size in the middle payload weight range.

All major sizing parameters of the candidate configurations were held constant in order that the aircraft represent scaled versions of a single design. In recognition of the limited range of engine sizes presently planned for commercial certification in the mid-1980's, an upper limit on single engine aircraft was established at 1200 horsepower (895 kw), and configurations requiring more horsepower were configured as twin engine aircraft.

Two major aircraft sizing parameters, wing loading and power loading, were established as representative of the current trend in ag-aircraft design. These parameters are shown for 21 current operational aircraft types in Figure 22. From this survey it was concluded that the trend is toward higher wing loading and lower weight per installed horsepower; therefore, for the candidate configurations a wing loading of 25 pounds per square foot (122 kg/sq. m.) and a power loading of 10 pounds per horsepower (6.08 kg/kw) were selected.

The influence of the range of payload densities from 33 pounds/cubic foot (529 kg/cu. m.) to 100 pounds/cu. foot (1603 kg/cu. m.) on the aircraft design is to produce a hopper volume variation of 3 to 1 for a given payload weight. To determine the influence of the resulting aircraft size variation on performance, two candidate configurations were established at each payload weight bracketing the payload density range, one providing a hopper sized to contain material of 33 pounds/cu. ft. and one sized to contain material of 100 pounds/cu. ft. To retain the effect of scaling a

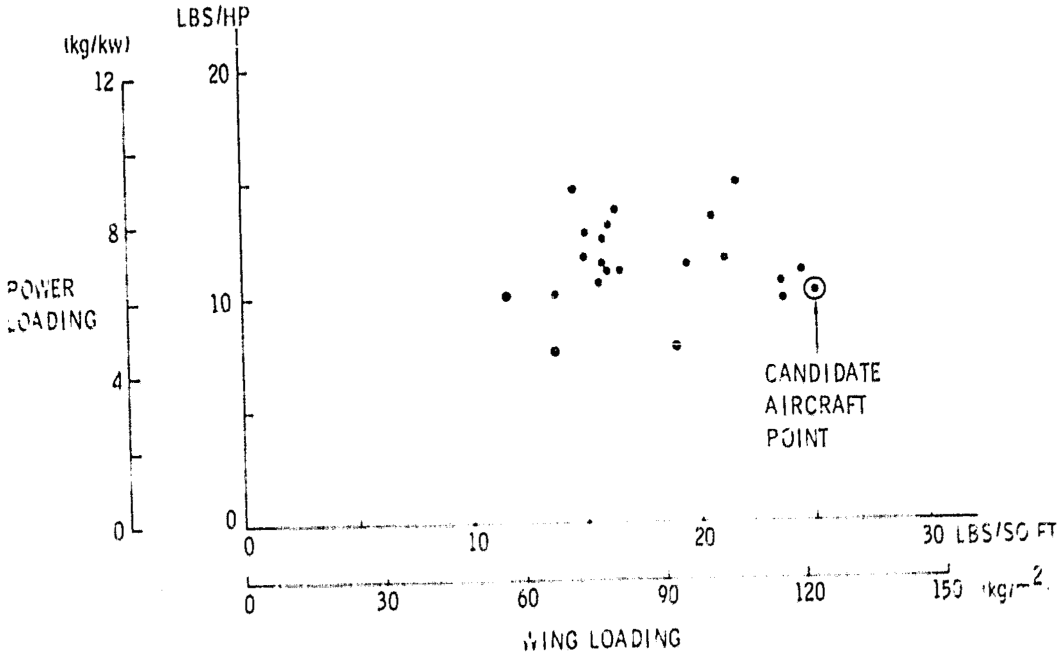


Figure 22. Wing Loading and Power Loading Current Agricultural Aircraft

single design, a standard hopper configuraion was established. This hopper design, shown in Figure 23, permits the center-of-gravity of the payload to be placed directly over the 0.25 mean aerodynamic chord (MAC) point of a wing with a straight, unswept 0.25 chord line.

A summary of weight and design data for the nine candidate configurations is presented in Table II, along with estimated acquisition costs and operating costs. The configuration designation codes are as follows: "C" designates candidate configuration; the first numeric entry designates the payload category in thousands of pounds; and the second numeric entry designates the material density value for which the aircraft was sized. For example, configuration C-1-33 is an aircraft with 1000 pounds payload sized to a material density value of 33 pounds/cu. ft.

Design layouts for the candidate aircraft are presented in Figure 24. The designs reflect powerplant selections consistent with availability predicted for the mid-1980's. Horizontally opposed reciprocating air cooled engines are used up to 400 horsepower. In the 400 to 1200 horsepower range, turboprop engines are used. All aircraft use conventional tailwheel landing gear to minimize weight and drag.

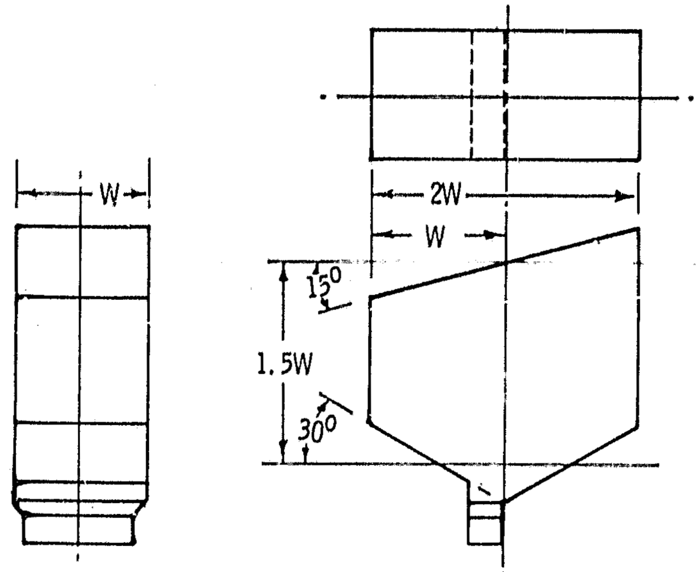
A drag analysis was conducted on each of the candidate aircraft and clean airplane drag polars established, as shown in Figure 25. Thrust versus flight speed was established using the method described in Section 3.4.

4.2 EVALUATION OF CANDIDATE CONFIGURATIONS

The candidate configurations were evaluated with the operations analysis model over a wide range of missions. Application rates were varied from 1 to 1000 pounds per acre (1 to 1121 kg/ha) in field sizes of 40, 160, and 360 acres (16.2, 64.8, and 145.7 ha). Resulting mission costs were then compared for the purpose of selecting two specific baseline design points offering good mission economics over different regions of the mission spectrum.

TABLE II - CANDIDATE CONFIGURATIONS

	C-1-33	C-1-100	C-3-33	C-3-100	C-4-33	C-6-33	C-6-100	C-10-33	C-10-100
PAYLOAD (LB)	1,000	1,000	3,000	3,000	4,500	6,500	6,500	10,000	10,000
EMPTY WEIGHT	1,440	1,405	3,440	3,200	5,600	7,925	7,145	12,260	10,885
GROSS WEIGHT (LB)	2,700	2,700	7,200	7,200	11,500	16,250	16,250	25,000	25,000
WING LOADING $(\frac{LBS}{SQ\ FT})$	25	25	25	25	25	25	25	25	25
POWER LOADING $(\frac{LBS}{H.P.})$	10	10	10	10	10	10	10	10	10
POWER PLANTS	1 x 290 H.P.	1 x 290 H.P.	1 x 750 H.P.	1 x 750 H.P.	1 x 1120 H.P.	2 x 850 H.P.	2 x 850 H.P.	2 x 1120 H.P.	2 x 1120 H.P.
ACQUISITION COST ($1,000)	35	34	181	177	292	414	396	708	670
OPERATING COST ($/FH)	33	32	97	95	144	218	210	328	312



$$W = \sqrt[3]{\frac{VOL.}{3}}$$

Figure 23. Standard Hopper Configuration

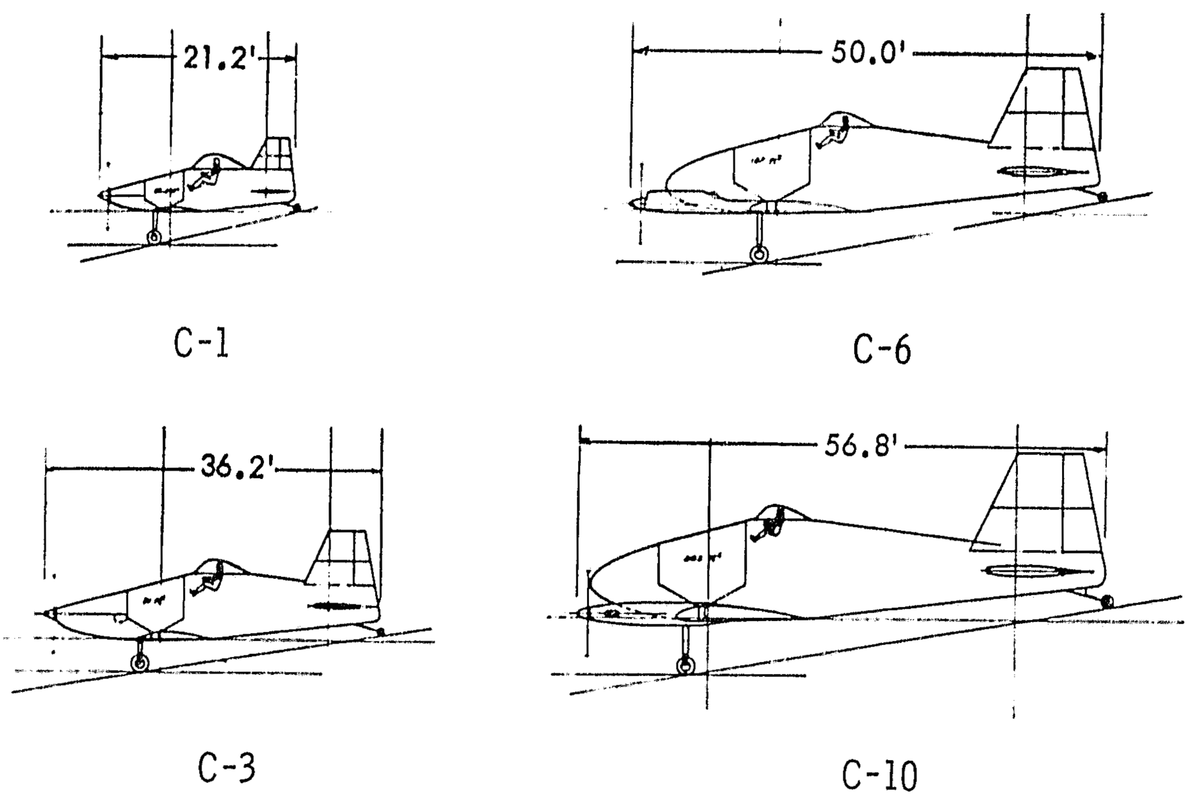


Figure 24. Candidate Aircraft Configurations

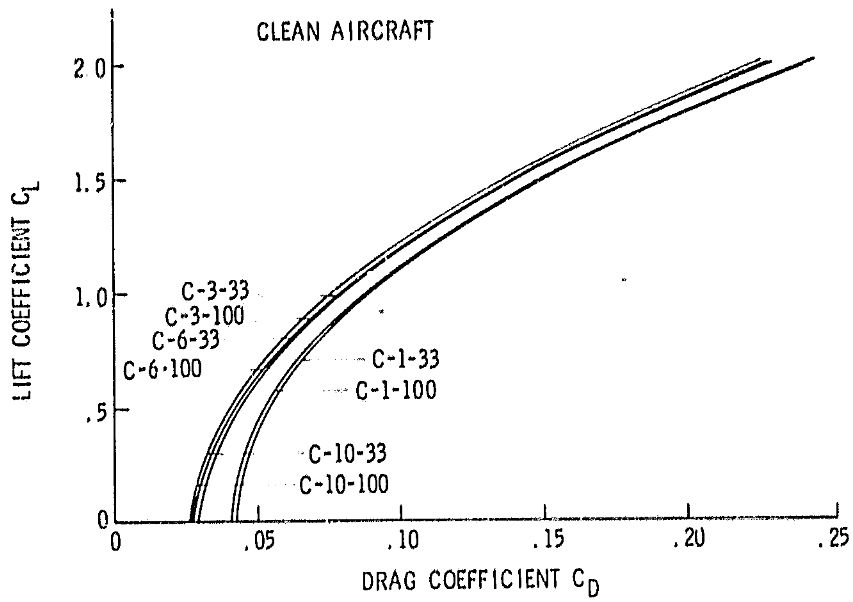


Figure 25. Candidate Aircraft Drag Polars

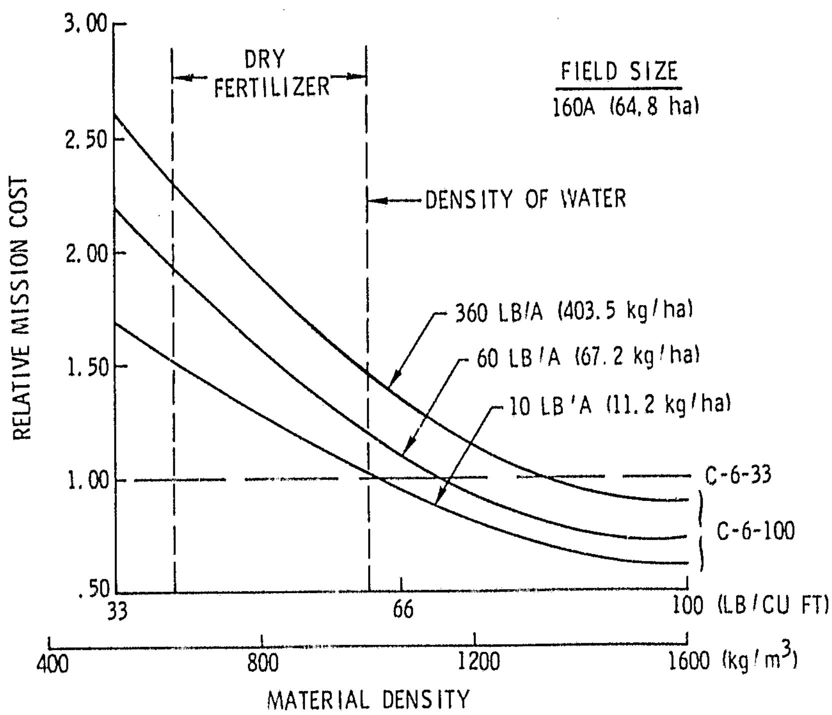


Figure 26. Mission Cost Versus Material Density (C-6 Configurations)

The first comparison was between aircraft sized to 33 pounds per cubic foot (529 kg/m^3) material density and those sized to 100 pounds per cubic foot (1603 kg/m^3). Figure 26 shows such a comparison for the C-6-33 aircraft versus the C-6-100 aircraft over a range of material density values. Three different application rates are shown, with C-6-100 values ploted as ratios of the corresponding C-6-33 values. It is seen that the -33 aircraft with the larger hopper is superior over most of the density range, up to and including the density of water which is representative of liquid applications. The -33 aircraft is significantly more cost effective in the lower density regions representative of fertilizers.

This comparison was even more favorable to the -33 configurations for lower payload aircraft and slightly less favorable for higher payload aircraft. In general, the superiority of -100 configurations is limited to a narrow range of high-density materials believed to be seldom encountered in aerial application work. For this reason, configurations sized to 100 pounds per cubic foot were dropped from further consideration.

The comparison of mission costs for the various size aircraft configured to 33 pounds per cubic foot density is shown in Figure 27. These results are based on liquid-dipersal operations with maximum allowed swath width of 1.5 times wing span for each respective configuration. The plots cover the entire range of application rates for a field size of 160 acres.

The most notable feature of the comparison is the performance of the 1000-pound (454 kg) payload aircraft, C-1-33. This small aircraft displays a slight economic advantage for application rates up to about 20 pounds per acre (22 kg/ha), but beyond that point the aircraft quickly becomes non-competitive. The other size aircraft are quite close in mission costs over the entire range of application rates. Lower payload aircraft have an advantage over the lower end of the spectrum, with a gradual shift to the higher payload aircraft at the high end. For smaller fields, the relationships shift slightly in favor of the smaller aircraft; for larger fields, slightly in favor of the larger aircraft.

Figure 28 provides a more meaningful comparison for purposes of selecting baseline payload points. Here the mission costs are plotted against aircraft payload for several different application rates. The low points in these curves would represent the payload design points best suited for particular missions. The curves are relatively flat, however, and there are no distinct inflection points that clearly lead to the selection of "best" baseline design points.

The comparison of candidate aircraft is summarized as follows:

- A small aircraft in the 1000-pound (454 kg) payload class is best for very low application rates, particularly in small fields.

- A very large aircraft in the 10,000-pound (4536 kg) class is best for extremely high application rates, particularly in large fields.

- Aircraft in the 3000 to 8000 pounds (1361 to 3629 kg) payload range are closely competitive over a broad range of missions, with an advantage to the smaller aircraft on the lower end of the mission spectrum and to the larger aircraft on the upper end.

After review of these results with the NASA program manager, the decision was made to select the two baseline design points at approximately 3000 pounds (1361 kg) payload and 7500 pounds (3402 kg) payload. The lower design point is representative in size of the larger agricultural aircraft now entering the market and provides the opportunity to examine design concepts for a single-engine turboprop configuration. Additionally, since this aircraft has good economic characteristics on the low end of the mission spectrum, beneficial technology applications should also be of value to smaller aircraft.

The large baseline design point, on the other hand, provides a good study point for advanced-concept aircraft of the future. This aircraft is more than twice as large as any existing agricultural aircraft and will require

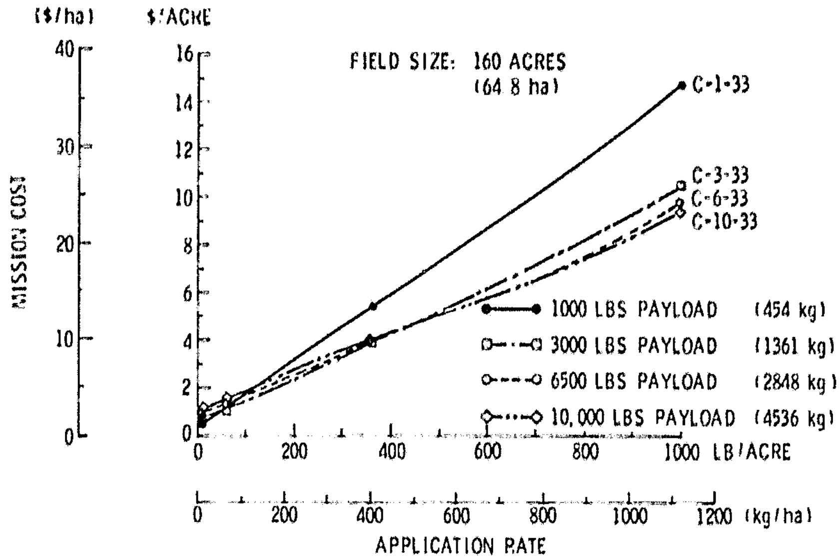


Figure 27. Comparative Mission Costs for Candidate Configurations

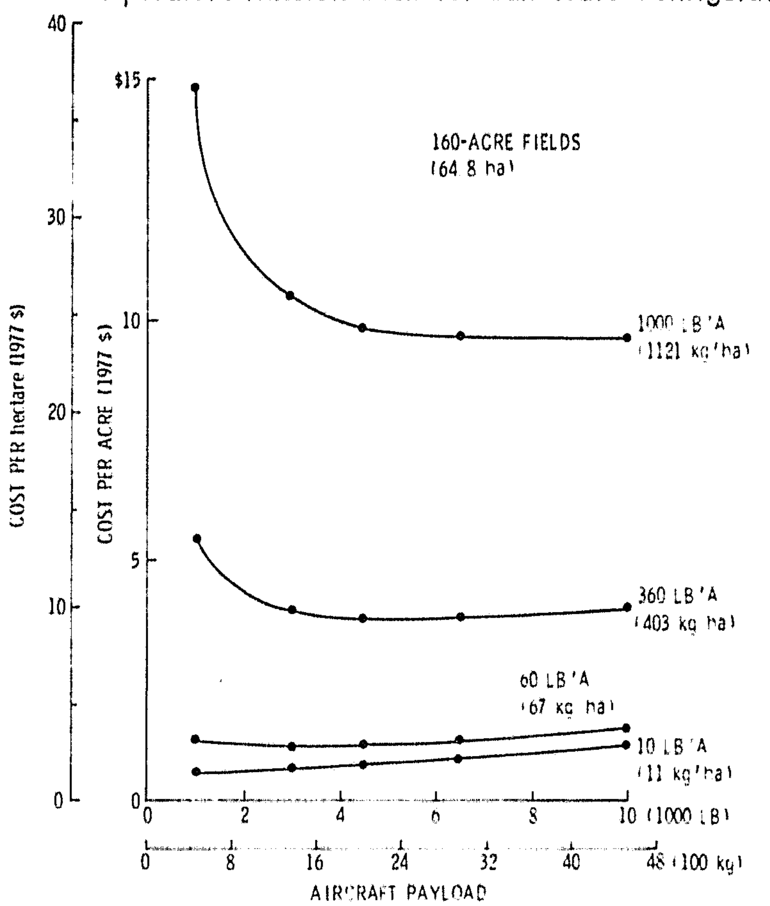


Figure 28. Mission Cost Versus Payload Capability

twin turboprop engines. A configuration of this type may benefit from different technology applications than smaller aircraft, and it allows evaluation of the potential utility of an aircraft of this size in agricultural missions.

4.3 INITIAL BASELINE AIRCRAFT

4.3.1 AGB-3-33 Baseline Aircraft

The small baseline aircraft is designated AGB-3-33. This aircraft retains most of the characteristics established for the candidate configurations but represents a somewhat more detailed preliminary design. A general arrangement of the aircraft is provided in Figure 29. The principal configuration parameters are listed in Table III.

The aircraft weight breakdown is presented in Table IV. On-board fuel weight is estimated to be that required for approximately three hours endurance at minimum fuel flow loiter speed of approximately 1.2 times stall speed. Fuselage weight reflects the assumption of an open truss, welded steel tubing structure with removable aluminum skin panels.

The design gross weight of the baseline aircraft is 5700 pounds. At this weight the FAR Part 23 limit maneuver load factor is 3.63. At this limit load factor the CAM-8 established restricted gross weight factor is 1.285, permitting an operational gross weight of 7300 pounds (3311 kg). A gross weight of 7300 pounds provides an operational payload of 3200 pounds (1452 kg) for the small baseline aircraft.

The AGB-3-33 clean airplane drag was estimated as described in Section 3.3. In addition, lift and drag characteristics were estimated for two wing flap arrangements: (1) simple, 25% chord, 60% span flaps, deflected 10° and 20°, and (2) simple, 25% chord, 100% span flaps, deflected 10° and 20°. These flap arrangements are considered most appropriate for use during heavily loaded take-off and possibly to aid in improving turn performance during dispersal operations. Drag polars for these cases are presented in Figure 30.

RESTRICTED GROSS WEIGHT –	7,300 LBS	(3,311 kg)
DESIGN GROSS WEIGHT –	5,700 LBS	(2,586 kg)
PAYLOAD WEIGHT –	3,200 LBS	(1,452 kg)
WING AREA –	288 SQ FT	(27 sq m)
INSTALLED HORSEPOWER –	730	
(KILOWATT) –	(544)	

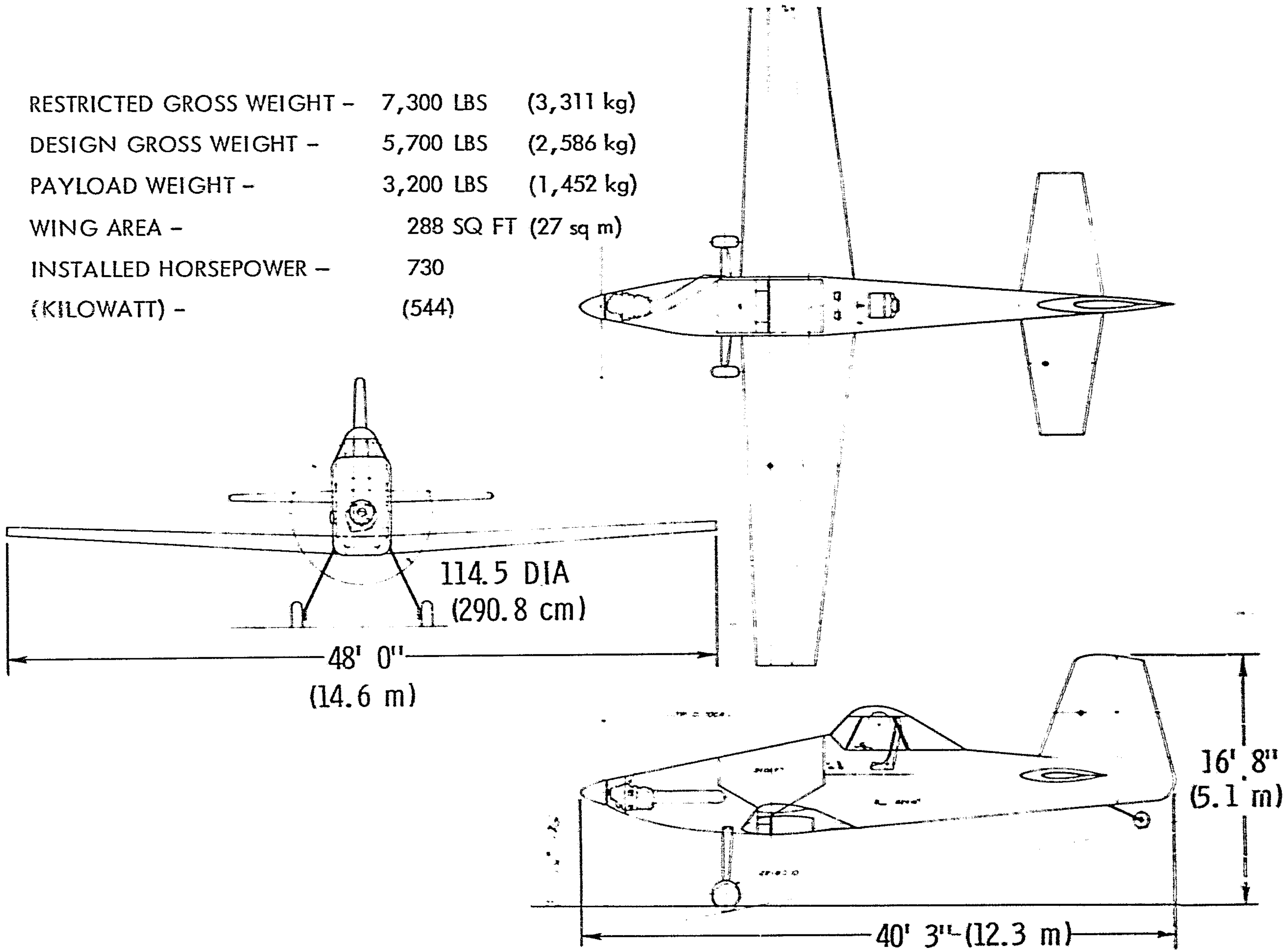


Figure 29. AGB-3-33 Baseline Configuration

TABLE III - AGB-3-33 CONFIGURATION PARAMETERS

RESTRICTED GROSS WEIGHT	7300 LB.	(3447 kg.)
DESIGN GROSS WEIGHT	5700 LB.	(2586 kg.)
RESTRICTED PAYLOAD WEIGHT	3200 LB.	(1452 kg.)
LIMIT MANEUVER LOAD FACTOR	3.63	
CAM 8 OVERLOAD FACTOR	1.285	
WING LOADING	25.0 LB/SQ. FT.	(122 kg/sq. m.)
WING AREA	292 SQ. FT.	(27.1 sq. m.)
WING SPAN	48.3 FT.	(14.7 m.)
ASPECT RATIO	8.0	
TAPER RATIO	.5	
AVERAGE THICKNESS RATIO	15%	
HORIZONTAL TAIL AREA	77.9 SQ. FT.	(7.2 sq. m.)
ASPECT RATIO	4.0	
VERTICAL TAIL AREA	44.9 SQ. FT.	(4.2 sq. m.)
ASPECT RATIO	1.0	
POWER LOADING	10 LBS./H.P.	(6.08 kg/kw)
INSTALLED HORSEPOWER	730 H.P.	(544 kw)

TABLE IV - AGB-3-33 WEIGHT BREAKDOWN

	WING	675 LB.	(306 kg)
	EMPENNAGE	130	(59 kg)
	FUSELAGE	950	(431 kg)
	LANDING GEAR	331	(150 kg)
	PROPULSION	773	(351 kg)
	A/C SYSTEMS	177	(80 kg)
	AG SYSTEMS	260	(118 kg)
EMPTY WEIGHT		3296	(1495 kg)
	PILOT	170	(77 kg)
OWE		3466	(1572 kg)
	FUEL	634	(288 kg)
ZERO PAYLOAD WT.		4100	(1860 kg)
	PAYLOAD	3200	(1451 kg)
RESTRICTED GROSS WT.		7300	(3311 kg)
FAR PART 23 GROSS WT.		5700	(2585 kg)

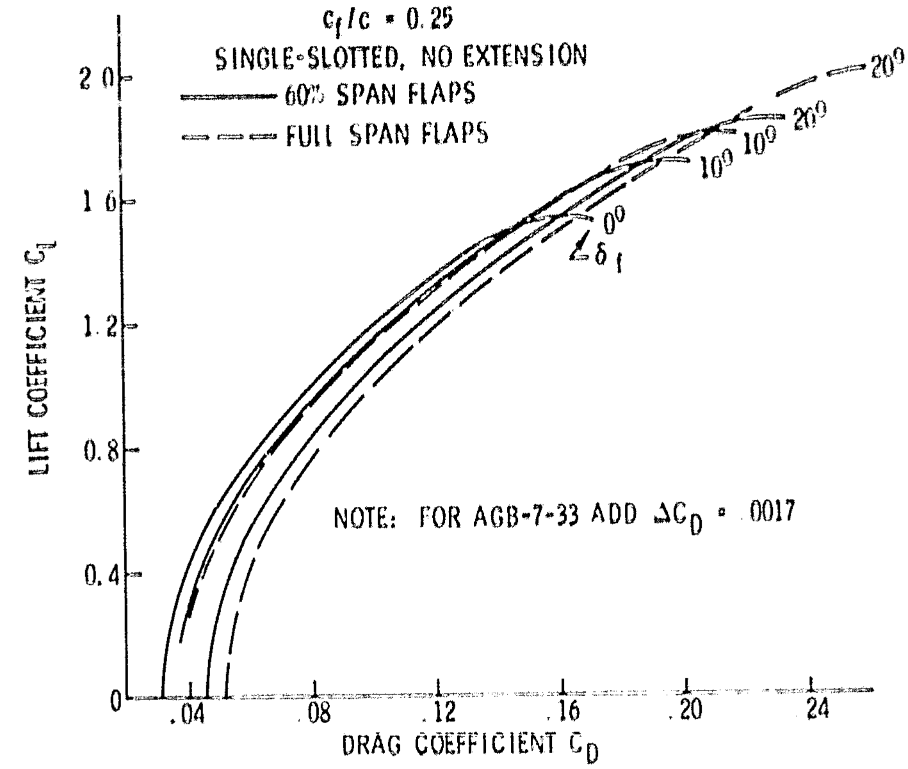


Figure 30. AGB 3-33 Drag Characteristics

To reduce the forward fuselage destabilizing moment and total wetted area, the baseline design employs a revised hopper design in which the vertical reference dimension is reduced from the 1.5 W of the standard hopper configuration to 1.0 W. The over-the-nose vision angle is 11 degrees. Cost estimates for the AGB-3-33 configuration are given in Table V.

4.3.2 AGB-7-33 Baseline Aircraft

The large baseline aircraft is designated AGB-7-33 and provides an operational payload of 7500 pounds. It represents the heaviest aircraft that could be certificated currently under FAR Part 23, with a design gross weight of 12,500 pounds.

The AGB-7-33 baseline general arrangement is presented in Figure 31, and the principal configuration parameters are listed in Table VI. The aircraft has a restricted operational gross weight of 15,300 pounds, as defined by a CAM-8 overload weight factor of 1.22 applied to the FAR Part 23 design gross weight. The CAM-8 weight factor is determined by a limit maneuver load factor of 3.16, as established by FAR Part 23.

The weight breakdown of aircraft AGB-7-33 is listed in Table VII. Fuel weight is estimated to be that required for approximately three hours endurance at minimum fuel flow loiter speed of approximately 1.2 times stall speed.

Drag polars for the clean configuration, and for flap cases of 60% span, 10° and 20° deflection, and 100% span 10° and 20° deflection were estimated from the data presented previously in Figure 30.

The 227 cubic foot (6.42 cu. m.) hopper is sized to provide 7500 pounds (3400 kg) of material of a density of 33 pounds/cu. ft. (530 kg/cu. m.). The hopper configuration is the revised shape used for the AGB-3-33 aircraft, providing an over-the-nose vision angle of 11 degrees.

The twin engine nacelles are wing mounted as close to the aircraft centerline as considered practical to avoid excessive interference drag and

TABLE V - AGB-3-33 BASELINE AIRCRAFT COST ESTIMATES

(1977 DOLLARS)

	AGB-3
ACQUISITION COST	193,000
OPERATING COST	
(PER FLIGHT HOUR)	
FUEL & OIL	22.30
ENGINE OVERHAUL	10.23
ANNUAL INSPECTION	3.64
UNSCHEDULED MAINTENANCE	7.48
HULL INSURANCE	16.79
LIABILITY INSURANCE	1.67
TAXES	0.37
MISCELLANEOUS	0.37
ANNUALIZED INVESTMENT	32.17
TOTAL	95.02

RESTRICTED GROSS WEIGHT –	15,300 LBS	(6,940 kg)
DESIGN GROSS WEIGHT –	12,500 LBS	(5,670 kg)
PAYLOAD WEIGHT –	7,500 LBS	(3,402 kg)
WING AREA –	612 SQ FT	(57 sq m)
INSTALLED HORSEPOWER –	2 X 750	
(KILOWATT) –	(2 x 559)	

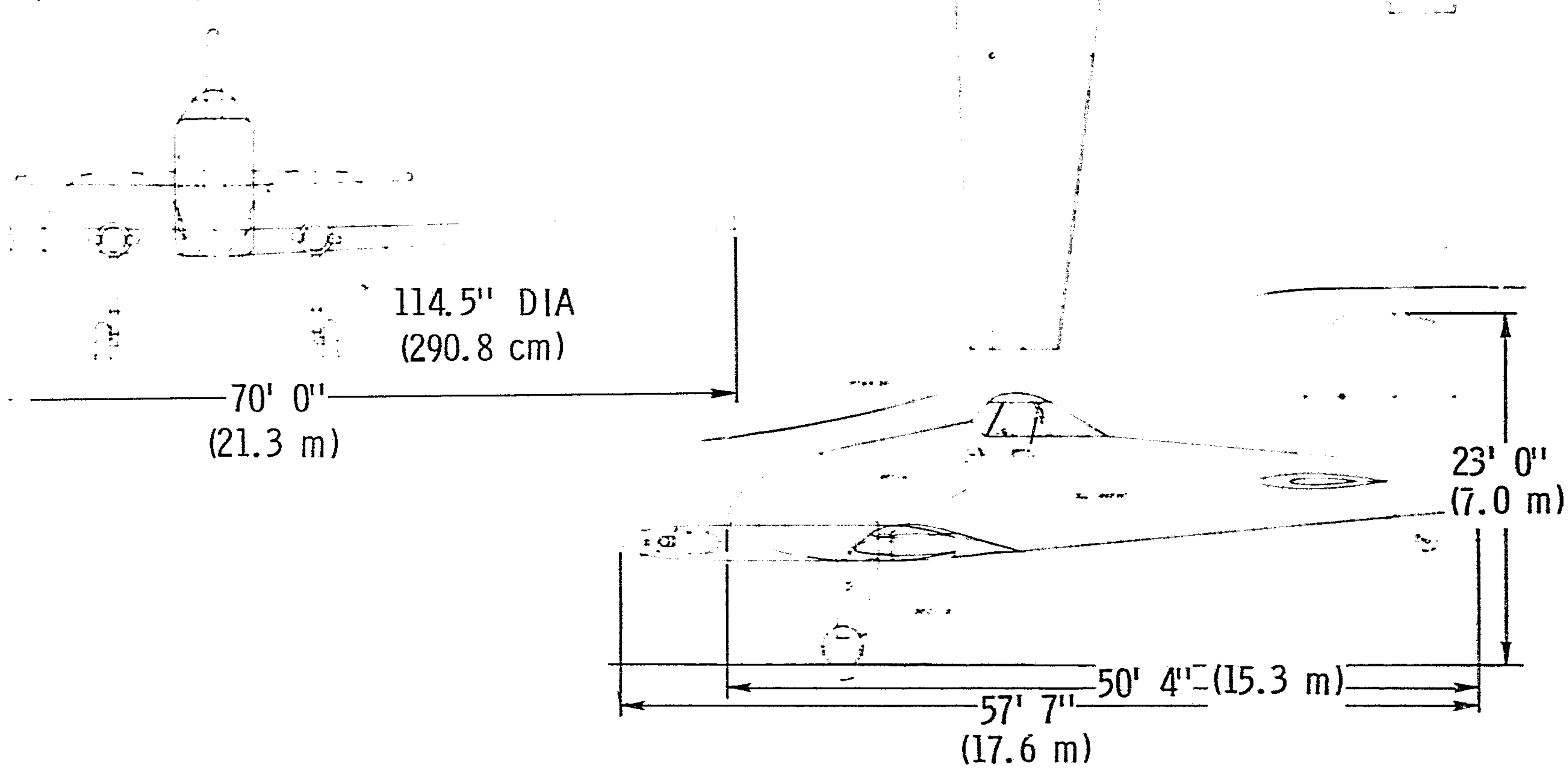


Figure 31. AGB-7-33 Baseline Configuration

TABLE VI - AGB-7-33 CONFIGURATION PARAMETERS

RESTRICTED GROSS WEIGHT	15,300 LB.	(6,940 kg.)
DESIGN GROSS WEIGHT	12,500 LB.	(5,670 kg.)
RESTRICTED PAYLOAD WEIGHT	7,500 LB.	(3,402 kg.)
LIMIT MANEUVER LOAD FACTOR	3.16	
CAM 8 OVERLOAD FACTOR	1.224	
WING LOADING	25.0 LB./SQ. FT.	(122 kg/sq. m.)
WING AREA	612 SQ. FT.	(56.9 sq. m.)
WING SPAN	70.0 FT.	(21.3 m.)
ASPECT RATIO	8.0	
TAPER RATIO	0.5	
AVERAGE THICKNESS RATIO	15%	
HORIZONTAL TAIL AREA	163 SQ. FT.	(15.1 sq. m.)
ASPECT RATIO	4.0	
VERTICAL TAIL AREA	94 SQ. FT.	(8.7 sq. m.)
ASPECT RATIO	1.0	
POWER LOADING	10 LB./H.P.	(6.08 kg/kw)
INSTALLED HORSEPOWER	1500 H.P.	(1119 kw)

TABLE VII - AGB-7-33 WEIGHT BREAKDOWN

	WING	1603 LB.	(727 kg)
	EMPENNAGE	257	(116 kg)
	FUSELAGE	1538	(698 kg)
	LANDING GEAR	660	(299 kg)
	PROPULSION	1560	(708 kg)
	A/C SYSTEMS	260	(118 kg)
	AG SYSTEMS	417	(189 kg)
EMPTY WEIGHT		6295	(2855 kg)
	PILOT	170	(77 kg)
OWE		6465	(2932 kg)
	FUEL	1335	(606 kg)
ZERO PAYLOAD WEIGHT		7800	(3538 kg)
	PAYLOAD	7500	(3402 kg)
RESTRICTED GROSS WEIGHT		15,300	(6940 kg)
FAR PART 23 GROSS WEIGHT		12,500	(5670 kg)

mutual propeller tip interference. These locations will minimize the one engine out yaw moment, and thereby maximize single engine controlability. Because of the light weight of the turbofan engines, long nacelles are required to balance the aircraft at the wing 25% MAC. To avoid excessive nacelle flexibility a small weight penalty will be imposed to stiffen the nacelle structure.

The fixed main landing gear struts are covered by fairings to minimize the drag.

Cost estimates for the AGB-7-33 configuration are given in Table VIII.

4.4 BASELINE OPTIMIZATION

The aircraft selected as baseline configurations were non-optimized versions of the candidate aircraft. Some optimization of these configurations was considered necessary prior to establishing baseline performance for reference in the design sensitivity studies. Studies were conducted to investigate the effect of wing loading, wing aspect ratio, and power loading on mission performance.

4.4.1 Wing Loading

The approach to this study was to hold payload weight constant and resize the aircraft for each wing loading, holding other parameters constant. Wing loadings of 15, 20, 25, 30 and 35 lbs/sq. ft. (73.2, 97.7, 122.1, 146.5, and 170.9 kg/sq. m.) were investigated. Aircraft sizing iterations were conducted at each wing loading, and corresponding aircraft characteristics were determined for each aircraft. Thrust, drag and cost estimates were made for each aircraft, and the data were analyzed for both liquid and dry material application missions using the operations analysis model. Configuration characteristics are listed for each small aircraft in Table IX.

Wing loading variations have two primary effects in the mission analysis: (1) effects on swath width resulting from changes in wing span as wing area

TABLE VIII - AGB-7-33 BASELINE AIRCRAFT COST ESTIMATES

(1977 DOLLARS)

	AGB-7
ACQUISITION COST	460,000
OPERATING COST (PER FLIGHT HOUR)	
FUEL & OIL	48.55
ENGINE OVERHAUL	22.46
ANNUAL INSPECTION	6.44
UNSCHEDULED MAINTENANCE	25.43
HULL INSURANCE	25.25
LIABILITY INSURANCE	1.67
TAXES	0.77
MISCELLANEOUS	0.52
ANNUALIZED INVESTMENT	76.67
TOTAL	207.76

TABLE IX - SMALL AIRCRAFT CONFIGURATION CHARACTERISTICS

WING LOADING OPTIMIZATION

WING LOADING, (LB./SQ. FT.)	15	20	25	30	35
WING AREA, (SQ. FT.)	537	380	292	237	200
WING SPAN (FT.)	65.5	55.1	48	43.5	40
RESTRICTED GROSS WEIGHT (LB.)	8050	7600	7300	7100	6950
INSTALLED HORSEPOWER	805	760	730	710	695
OPERATING COST ($/HR.)	106.52	99.96	95.02	91.03	88.18

varies; and (2) effects on operating cost of resizing the aircraft, including changes in engine horsepower to maintain constant power loading. In the first case, with constant aspect ratio, a decrease in wing loading produces an increase in wing span with a corresponding improvement in swath-width capability. In the second case, a decrease in wing loading causes the aircraft to increase in size, including larger wing and empennage and a corresponding increase in horsepower, all of which result in higher operating cost. An increase in wing loading produces opposite effects in both cases.

The effect of wing loading on mission productivity is shown in Figure 32 for an application rate of 100 lbs/acre (112.1 kg/ha) on a field size of 160 acres (64.8 ha). Productivity decreases essentially lineally with increasing wing loading. This reflects directly the decrease in swath width with decreasing wing size.

Mission cost is presented in Figure 33. The impact of the increase in operating cost with increasing airplane size that accompanies a decrease in wing loading can be seen. The slight productivity increase of the dry mission with decreasing wing loading does not compensate for increasing cost, and minimum cost is achieved in the range of 25 to 30 lbs/sq. ft. (122 to 146 kg/sq. m.). The more rapid increase in productivity with decreasing wing loading of the liquid mission overrides the increase in cost, resulting in a continuing reduction in mission cost to 15 lbs/sq. ft. (73 kg/sq. m.). Because of the improved mission cost for liquid missions and the fact that lower wing loading is favorable to improved field performance, a decision was made to decrease the wing loading of the small baseline aircraft to 20 lbs/sq. ft. (98 kg/sq. m.). This change has virtually no effect on dry material mission costs.

A similar investigation was conducted on the large baseline aircraft over the same range of wing loadings. The characteristics of these aircraft are listed in Table X. The effects of wing loading on mission productivity for an application rate of 400 lbs/acre (448.3 kg/ha) on a field size of 360 acres (145.7 ha) are shown in Figure 34. Productivity of the dry material mission is 10% to 15% lower than that of the liquid mission and increases

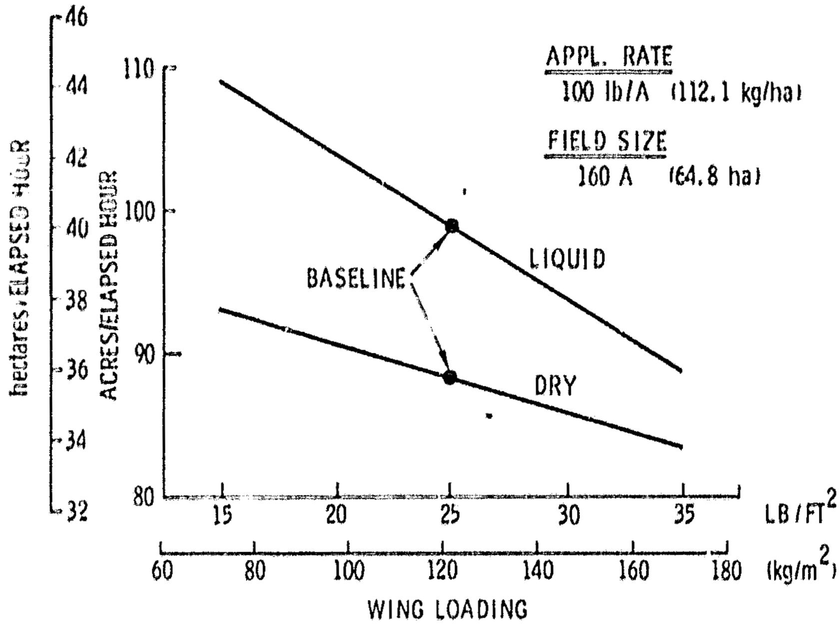


Figure 32. Effects of Wing Loading (AGB-3-33)

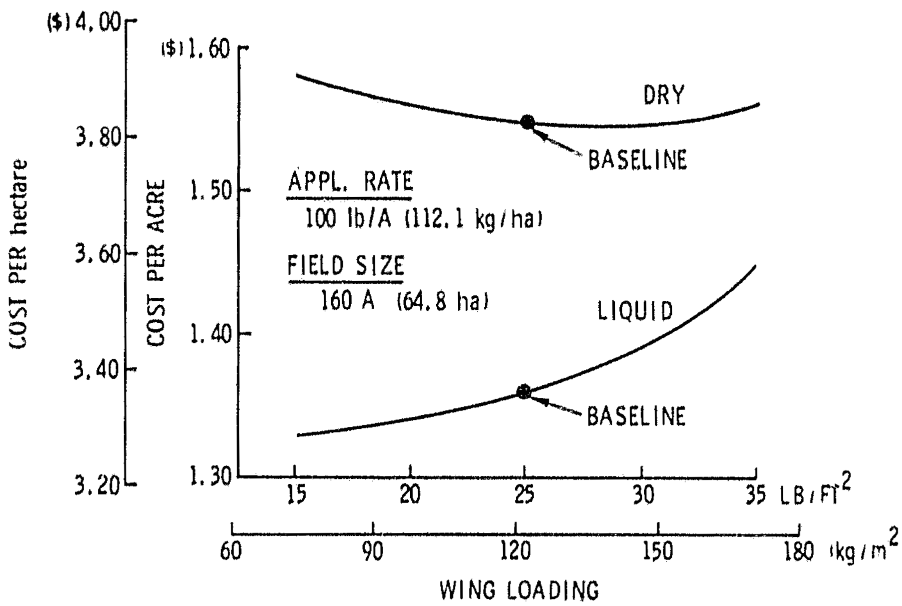


Figure 33. Effects of Wing Loading (AGB-3-33)

TABLE X - LARGE AIRCRAFT CONFIGURATION CHARACTERISTICS

WING LOADING OPTIMIZATION

WING LOADING LB./SQ. FT.	15	20	25	30	35
WING AREA, SQ. FT.	1133	800	612	495	414
WING SPAN, FT.	95.2	90	70	62.9	57.5
RESTRICTED GROSS WEIGHT, LBS.	17,000	16,000	15,300	14,850	14,500
INSTALLED HORSEPOWER	1700	1600	1530	1485	1450
OPERATING COST $/HR.	244.12	223.34	207.76	196.13	187.19

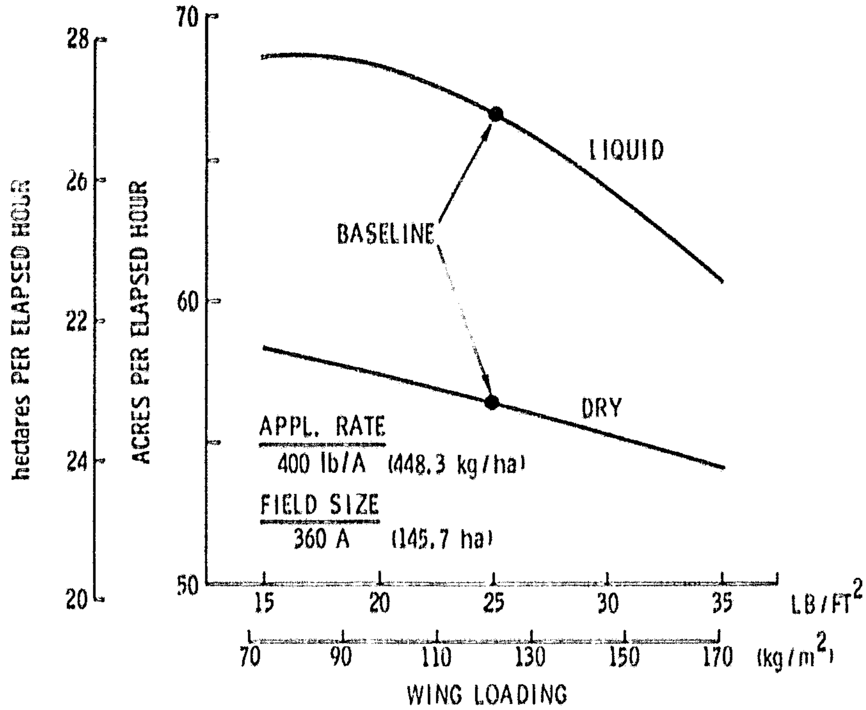


Figure 34. Effects of Wing Loading (AGB-7-33)

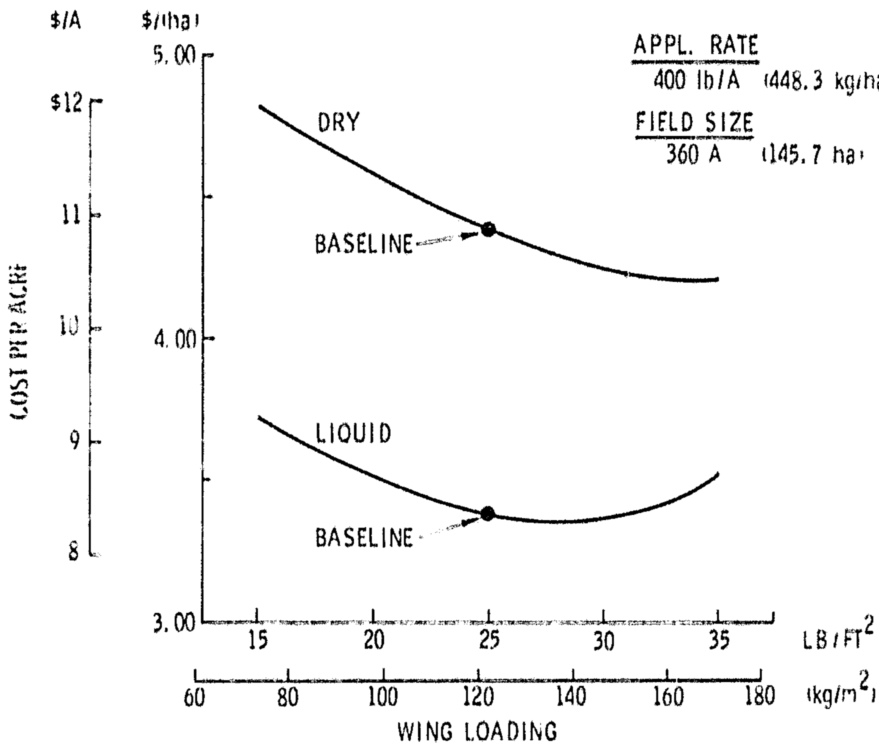


Figure 35. Effects of Wing Loading (AGB-7-33)

continuously as the wing loading decreases. The productivity of the liquid mission peaks in the region of 15 to 20 lbs/sq. ft. (73 to 98 kg/sq. m.). This effect appears to reflect the large pumping power requirements that occur at the combination of high application rate and large wingspan. The large pumping power extraction reduces thrust available for flight, limiting the swath width and swath speed of the aircraft at the low wing loadings.

Mission costs are indicated for the large aircraft in Figure 35. The higher productivity of the liquid mission results in lower mission costs at all wing loadings. The decrease in aircraft cost with aircraft size as the wing loading increases results in lowest cost at a wing loading somewhat higher than the baseline value. The decrease in cost is relatively small, however, and because the takeoff field length increases rapidly with wing loading the decision was made to retain the 25 lbs/sq. ft. (122 kg/sq. m.) wing loading on the large baseline aircraft.

4.4.2 Aspect Ratio

The approach for this study was to hold the gross weight and wing loading constant and vary the payload weight as the wing and fuselage weight change with aspect ratio. Aspect ratio was investigated over a range from 6 to 12. Wing weight was computed for each aspect ratio. The change in fuselage weight resulting from change in tail length with change in wing MAC was also determined. The total change in structural weight was then compensated for by an equal and opposite change in payload weight. The changes in drag and operational cost created by the changes in aspect ratio and empty weight were determined, and each case was analyzed with the operations analysis model. The configuration characteristics for each aspect ratio case are listed in Table XI.

Because of effect on wing span, aspect ratio in agricultural aircraft design has an effect on swath width as well as induced drag and wing weight. Productivity of the small aircraft for both liquid and dry application missions at 100 lbs/acre (112.1 kg/ha) on 160 acre (64.8 ha) fields is shown in Figure 36 as a function of aspect ratio. Liquid mission

TABLE XI - AIRCRAFT CONFIGURATION CHARACTERISTICS

ASPECT RATIO OPTIMIZATION

ASPECT RATIO	6	8	10	12
SMALL AIRCRAFT				
WING SPAN (FT.)	41.6	48	53.7	58.8
CAM 8 PAYLOAD WEIGHT (LB.)	3200	3[illegible]00	3080	2960
LARGE AIRCRAFT				
WING SPAN (FT.)	60.6	70	78.2	85.7
CAM 8 PAYLOAD WEIGHT, (LB)	7800	7500	7200	6920

C-2

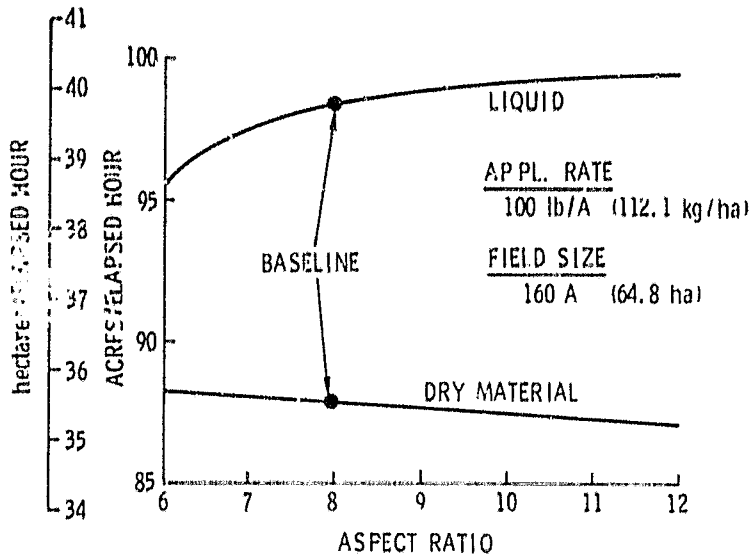


Figure 36. Effects of Aspect Ratio (AGB-3-33)

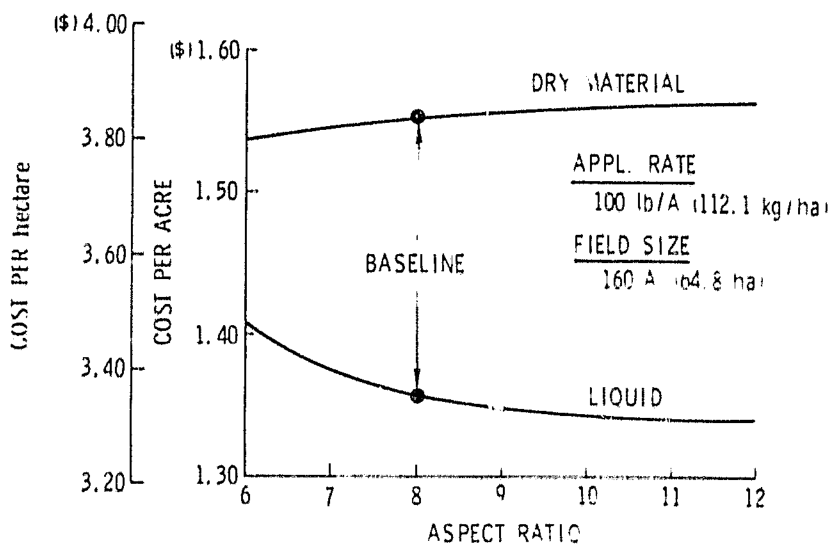


Figure 37. Effects of Aspect Ratio (AGB-3-33)

performance continues to increase across the range of aspect ratio considered. This reflects the influence of increasing swath width with wing span. The rate of increase becomes less as aspect ratio increases, however, due to the increasing loss of payload to wing weight and loss of swath speed to pumping power requirements.

Dry material application performance decreases with aspect ratio due to the loss of payload weight overriding the effect of decreasing drag as aspect ratio increases. The dry mission performance varies from 7% less than that of the liquid at aspect ratio 6 to 13% less at aspect ratio 12.

The mission costs of the small airplane are presented in Figure 37 for both liquid and dry missions. The decrease in productivity and increase in operating cost with aspect ratio result in the cost of the dry application increasing slightly with aspect ratio. The increase in productivity of the liquid mission with aspect ratio overrides the increase in operational cost resulting in an improvement in mission cost with increasing aspect ratio. The rate of improvement above aspect ratio 8 is relatively small, however, and because of this the decision was made to retain the aspect ratio of 8 selected initially for the baseline.

Productivity of the large aircraft in liquid and dry applications of 400 lbs/acre (448.3 kg/ha) on 360 acre (145.7 ha) fields is shown in Figure 38. The aircraft achieves maximum productivity in the range of aspect ratio 7 to 8. For the liquid system, the dominant effects are a reduction in payload due to wing weight increase with aspect ratio plus an increase in pumping power extraction with increasing wingspan. These detrimental effects are greater than the effect of increasing swath width above aspect ratio 8. For dry material dispersal the effect of loss of payload is greater than the effect of decreasing drag.

The mission costs with varying aspect ratio for the large aircraft are shown in Figure 39. The relationship of productivity and operational costs produce a minimum cost/acre for both liquid and dry applications at an aspect ratio of approximately 7. Because the mission cost variations are

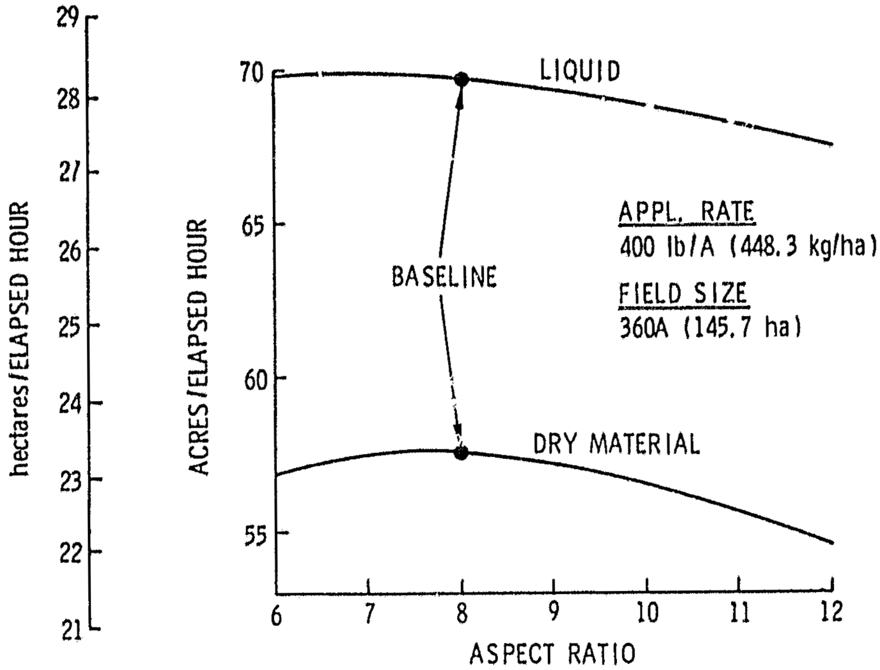


Figure 38. Effects of Aspect Ratio (AGB-7-33)

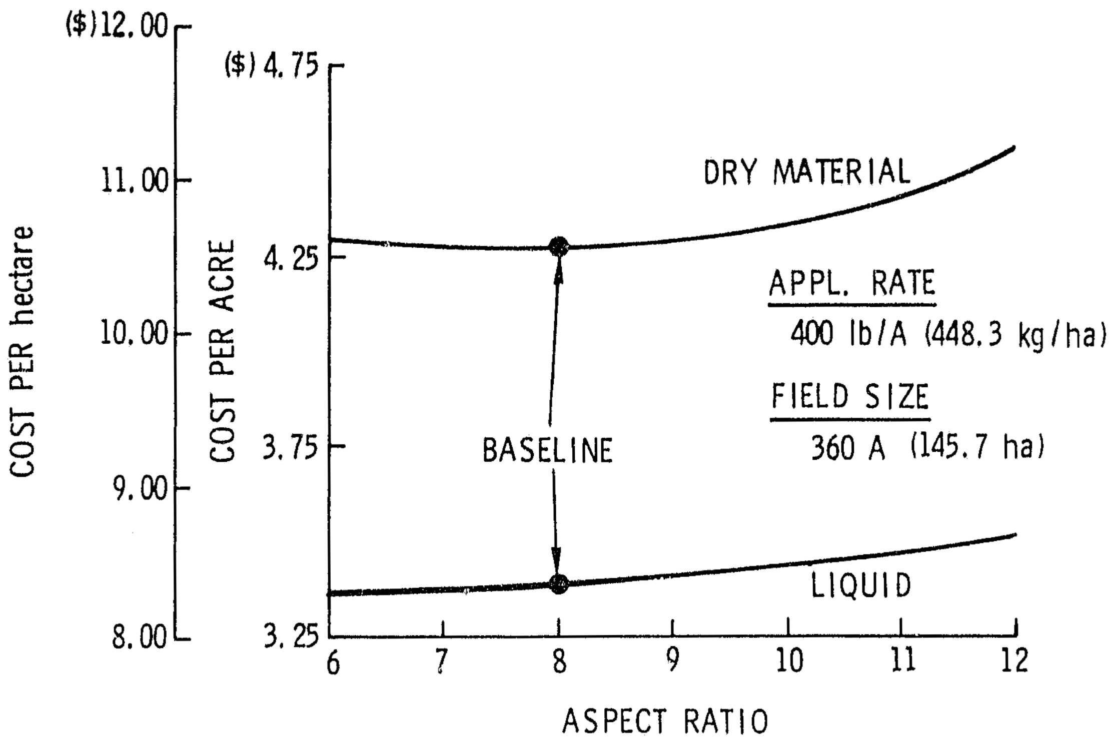


Figure 39. Effects of Aspect Ratio (AGB-7-33)

so slight in the region of minimum cost, the decision was made to retain the large aircraft aspect ratio 8 previously selected.

4.4.3 Power Loading

An analysis was made of the effect of variations in power loading from the 10 lbs/H.P. (6 kg/kw) selected for the candidate configurations. The approach to this study was to hold the gross weight and wing loading constant and vary payload weight as the propulsion system weight changed as a result of variations in power loading. Power level was varied over a range from 20% less to 20% greater than that of the baseline. Changes in installed thrust and airplane operating cost were determined for each installed horsepower, and the aircraft were then analyzed with the operations analysis model. The configuration characteristics are listed in Table XII.

In Figure 40 the change in mission productivity is shown as a function of change in power level from that of the small baseline aircraft applying both liquid and dry material at 100 lbs/acre (112.1 kg/ha) on 160 acre (64.8 ha) fields. Productivity varies directly with power level for both liquid and dry missions, although the rate of change is lower for the liquid mission. The variation of mission cost with power level is shown in Figure 41. For both liquid and dry missions the reduction in operating cost overcomes the reduction in productivity as the power level is reduced to approximately -15%, being essentially linear to -10%. The major cost factor is the high cost per unit of power of the turboprop engines, which is reflected in operating cost through the annualized investment cost term. Although a decrease in power level reduces takeoff field performance somewhat, the improvement in mission cost achieved by a 10% reduction in installed power is considered worthwhile; consequently, a decision was made to reduce the installed power of the small baseline aircraft by 10%.

Change in productivity for the large baseline aircraft is shown in Figure 42 as a function of change in power level for an application rate of 400 lbs/acre (448.3 kg/ha) on 360 acre (145.7 ha) fields. The changes in productivity of the missions are essentially direct with change in power

TABLE XII - AIRCRAFT CONFIGURATION CHARACTERISTICS

POWER LOADING OPTIMIZATION

POWER LOADING CHANGE	-20%	-10%	0	+10%	+20%
SMALL AIRCRAFT					
INSTALLED HORSEPOWER	600	675	750	825	900
PAYLOAD WEIGHT, LBS	3380	3290	3200	3110	3020
OPERATING COST, $/HR	88.44	94.00	99.26	104.72	109.68
LARGE AIRCRAFT					
INSTALLED HORSEPOWER	1200	1350	1500	1650	1800
PAYLOAD WEIGHT, LBS	7820	7660	7500	7340	7180
OPERATING COST $/HR	185.98	196.88	207.76	218.48	229.36

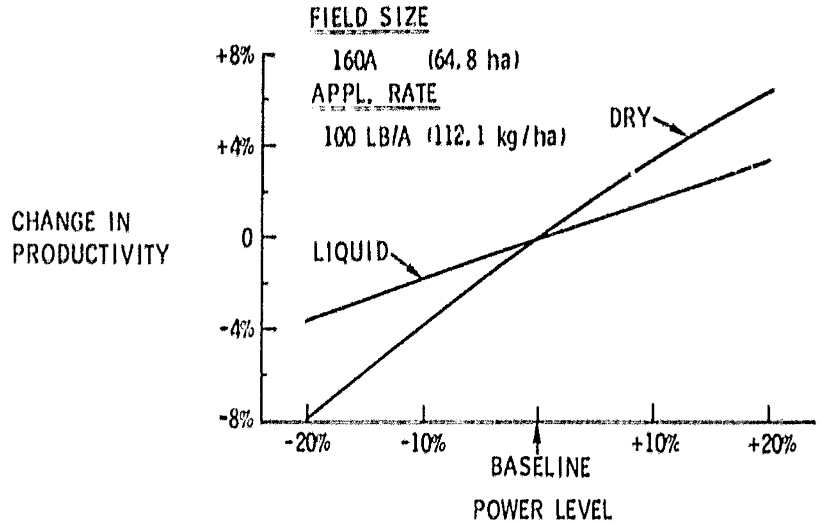


Figure 40. Effects of Power Loading (AGB-3-B3)

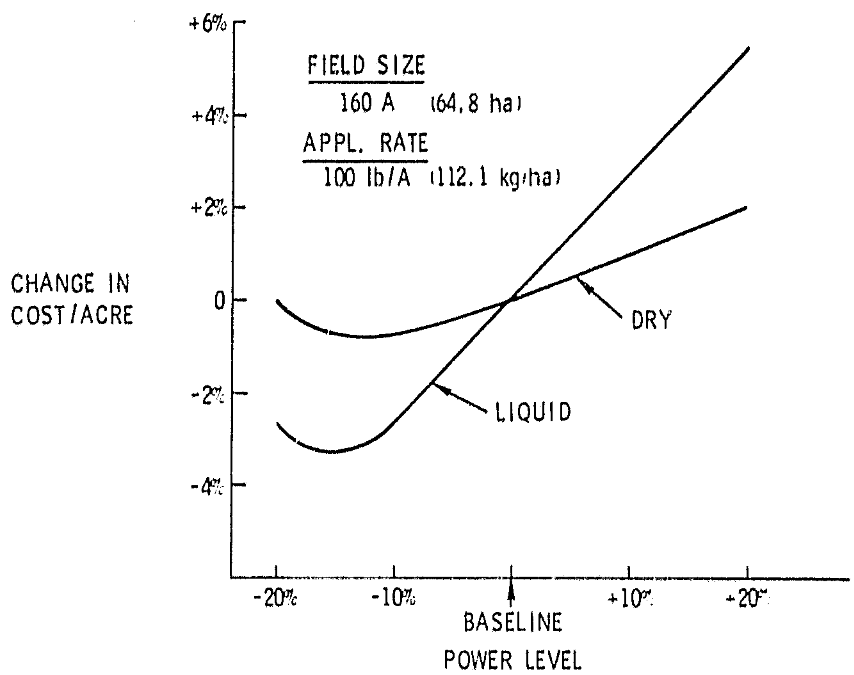


Figure 41. Effects of Power Loading (AGB-3-B3)

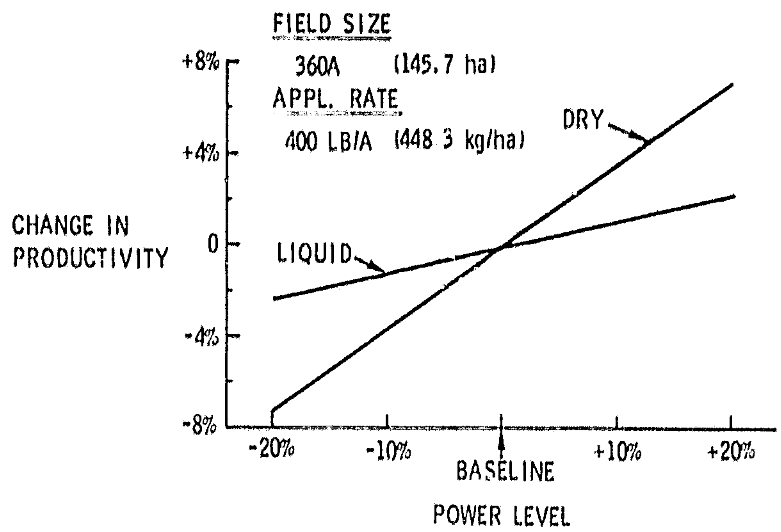


Figure 42. Effects of Power Loading (AGB-7-33)

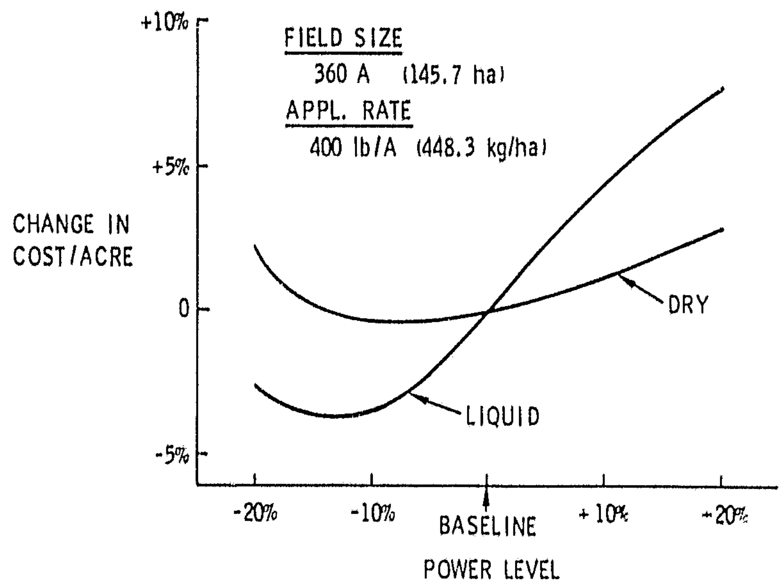


Figure 43. Effects of Power Loading (AGB-7-33)

level, with a lower rate of change for the liquid mission. Mission cost change as a function of change in power level is shown in Figure 43. The characteristics are similar to those of the small baseline aircraft, providing a cost improvement with decreasing power to approximately -10%; however, the cost savings for the higher rate dry material applications are very small. Because the cost savings appear significant for the liquid mission, it was decided to reduce the installed power loading of the large baseline aircraft by 10%.

4.5 SELECTED BASELINE AIRCRAFT

The optimization studies resulted in several changes to the initial baseline aircraft, and the modified aircraft designs are redesignated the AGB-3-B4 for the small aircraft and the AGB-7-B1 for the large aircraft. These configurations form the final baseline aircraft for the study program. Mission productivity data for these aircraft over a wide range of missions are given in Section 7.1.

4.5.1 AGB-3-B4 Baseline Aircraft

The baseline small aircraft configuration general arrangement is shown in Figure 44, and a list of principal design parameters is provided in Table XIII.

The aircraft weight breakdown is presented in Table XIV. Restricted category gross weight is 7600 pounds (3447 kg), and restricted payload weight is 3200 pounds (1452 kg). The design gross weight for FAR Part 23 certification is 5925 pounds (2688 kg) at a design limit maneuver load factor of 3.61. At this load factor the CAM-8 restricted gross weight factor is 1.283.

The wing loading of the AGB-3-B4 aircraft is 20 lbs/sq. ft. (98 kg/sq. m.) with a wing area of 380 sq. ft. (35.3 sq. m.). Full span, 25% chord simple hinged flaps deflected 20° are incorporated for use during takeoff. Roll control will be provided by a combination of outboard spoilers and flaperons utilizing an outboard segment of the flaps.

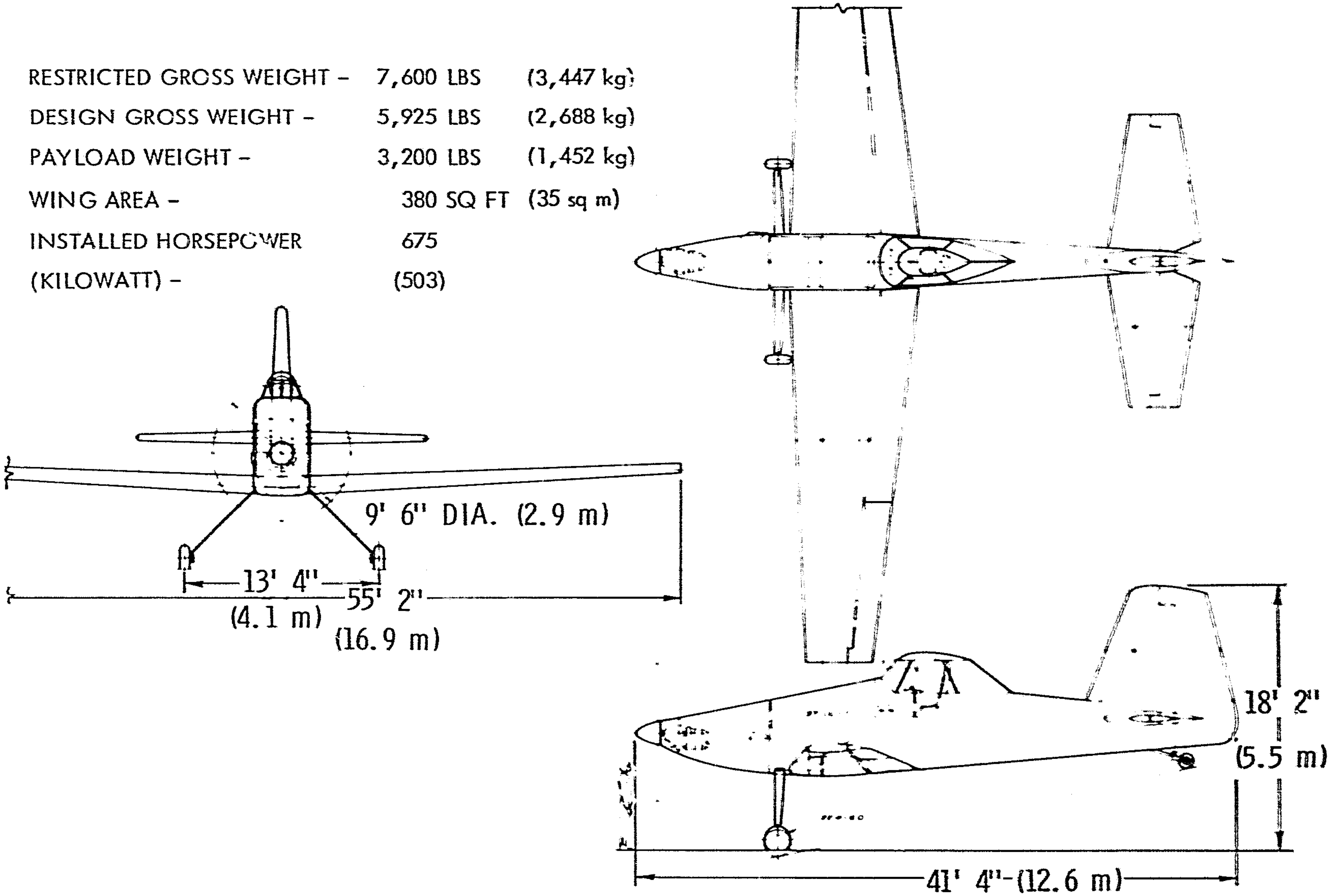


Figure 44. AGB-3-B4 Baseline Configuration

TABLE XIII - AGB-3-B4 CONFIGURATION PARAMETERS

RESTRICTED GROSS WEIGHT	7600 LB.	(3447 kg.)
DESIGN GROSS WEIGHT	5925 LB.	(2688 kg.)
RESTRICTED PAYLOAD WEIGHT	3200 LB.	(1452 kg.)
LIMITED MANEUVER LOAD FACTOR	3.61	
CAM 8 OVERLOAD FACTOR	1.283	
WING LOADING	20.0 LB./SQ. FT.	(97.7 kg/sq. m.)
WING AREA	380. SQ. FT.	(35.3 sq. m.)
WING SPAN	55.1 FT.	(16.8 m)
ASPECT RATIO	8.0	
TAPER RATIO	0.5	
AVERAGE THICKNESS RATIO	15%	
HORIZONTAL TAIL AREA	101 SQ. FT.	(9.4 sq. m.)
ASPECT RATIO	4.0	
VERTICAL TAIL AREA	58 SQ. FT.	(5.4 sq. m.)
ASPECT RATIO	1.0	
POWER LOADING	11.3 LB./H.P.	(6.87 kg/kw)
INSTALLED HORSEPOWER	675 H.P.	(503 kw)

TABLE XIV - AGB-3-B4 WEIGHT BREAKDOWN

	WING	855 LB.	(388 kg)
	EMPENNAGE	158	(72 kg)
	FUSELAGE	934	(424 kg)
	LANDING GEAR	344	(156 kg)
	PROPULSION	832	(377 kg)
	A/C SYSTEMS	180	(81 kg)
	AG SYSTEMS	265	(120 kg)
EMPTY WEIGHT		3568	(1618 kg)
	PILOT	170	(77 kg)
OWE		3738	(1696 kg)
	FUEL	662	(300 kg)
ZERO PAYLOAD WT.		4400	(1996 kg)
	PAYLOAD	3200	(1451 kg)
RESTRICTED GROSS WT.		7600	(3447 kg)
FAR PART 23 GROSS WT.		5925	(2688 kg)

A turboprop engine of 675 installed shaft horsepower (503 kw) provides a power loading of 11.3 pounds/HP (6.9 kg/KW).

Cost estimates for the refined small baseline aircraft are given in Table XV.

4.5.2 AGB-7-B1 Baseline Aircraft

The baseline large aircraft configuration general arrangement is essentially the same as that of the AGB-7-33 presented previously. A list of the principal design parameters for the AGB-7-B1 are listed in Table XVI.

The weight breakdown of the aircraft is presented in Table XVII. The restricted gross weight of the aircraft is 15,300 pounds (6940 kg), providing a restricted paylod of 7600 pounds (3447 kg). The design gross weight is 12,500 pounds (5670 kg), resulting in a limit maneuver load factor of 3.16, and a CAM-8 weight factor of 1.224.

The wing loading is 25 lbs./sq. ft. (122 kg/sq. m.), with a wing area of 612 sq. ft (57 sq. m.). Full span, 25% chord simple hinged flaps with a 20° deflection are employed for takeoff. Roll control will be provided by a combination of spoilers and flaperons.

Two turboprop engines of 688 installed horsepower (513 kw) each are incorporated in the wing mounted nacelles, resulting in an installed power loading at restricted gross weight of 11.1 lbs./H.P. (6.8 kg/kw).

Cost estimates for the refined large baseline aircraft are given in Table XVIII.

4.6 DESIGN SENSITIVITY STUDIES

4.6.1 Approach

Parametric sensitivity studies were performed with the baseline configurations for all of the major design characteristics that can be varied in the

TABLE XV - AGB-3-B4 BASELINE AIRCRAFT COST ESTIMATES

(1977 DOLLARS)

ACQUISITION COST	202,000
OPERATING COST (PER FLIGHT HOUR)	
FUEL & OIL	22.42
ENGINE OVERHAUL	10.29
ANNUAL INSPECTION	3.75
UNSCHEDULED MAINTENANCE	8.24
HULL INSURANCE	17.41
LIABILITY INSURANCE	1.67
TAXES	0.37
MISCELLANEOUS	0.38
ANNUALIZED INVESTMENT	33.67
TOTAL	98.20

TABLE XVI - AGB-7-B1 CONFIGURATION PARAMETERS

RESTRICTED GROSS WEIGHT	15,300 LB.	(6940 kg.)
DESIGN GROSS WEIGHT	12,500 LB.	(5670 kg.)
RESTRICTED PAYLOAD WEIGHT	7,600 LB.	(3447 kg.)
LIMIT MANEUVER LOAD FACTOR	3.16	
CAM 8 OVERLOAD FACTOR	1.224	
WING LOADING	25.0 LB./SQ. FT.	(122 kg/sq. m.)
WING AREA	612 SQ. Ft.	(56.9 sq. m.)
WING SPAN	70.0 FT.	(21.3 m.)
ASPECT RATIO	8.0	
TAPER RATIO	0.5	
AVERAGE THICKNESS RATIO	15%	
HORIZONTAL TAIL AREA	163 SQ. FT.	(15.1 sq. m.)
ASPECT RATIO	4.0	
VERTICAL TAIL AREA	94 SQ. FT.	(8.7 sq. m.)
ASPECT RATIO	1.0	
POWER LOADING	11.1 LB./H.P.	(6.76 kg/kw)
INSTALLED HORSEPOWER	1377 H.P.	(1027 kw)

TABLE XVII - AGB-7-B1 WEIGHT BREAKDOWN

	WING	1594 LB.	(723 kg)
	EMPENNAGE	257	(117 kg)
	FUSELAGE	1310	(594 kg)
	LANDING GEAR	663	(301 kg)
	PROPULSION	1680	(762 kg)
	A/C SYSTEMS	262	(119 kg)
	AG SYSTEMS	417	(189 kg)
EMPTY WEIGHT		6183	(2805 kg)
	PILOT	170	(77 kg)
OWE		6353	(2882 kg)
	FUEL	1347	(611 kg)
ZERO PAYLOAD WEIGHT		7700	(3493 kg)
	PAYLOAD	7600	(3447 kg)
RESTRICTED GROSS WEIGHT		15,300	(6940 kg)
FAR PART 23 GROSS WEIGHT		12,500	(5670 kg)

TABLE XVIII - AGB-7-B1 BASELINE AIRCRAFT COST ESTIMATES

(1977 DOLLARS)

ACQUISITION COST	429,000
OPERATING COST (PER FLIGHT HOUR)	
FUEL & OIL	44.63
ENGINE OVERHAUL	20.63
ANNUAL INSPECTION	6.21
UNSCHEDULED MAINTENANCE	24.99
HULL INSURANCE	24.31
LIABILITY INSURANCE	1.67
TAXES	0.77
MISCELLANEOUS	0.51
ANNUALIZED INVESTMENT	71.50
TOTAL	195.22

operations analysis model. The technique is to change the value of a given parameter in the model input data while holding all other parameters constant. The aircraft is then flown through a selected mission in the model, and the effects of the parameter change are examined in terms of changes in mission productivity and/or mission cost relative to the baseline configuration. The sensitivity data thus provide measures of the relative effects of the major design characteristics on aircraft mission performance.

These studies are purely parametric in that no attempt is made to define physical methods by which the changes in design characteristic would be obtained. The studies do not reflect any increase or decrease in aircraft acquisition cost or operating cost that might occur as a result of a particular design change. Consequently, the mission results reflect changes in aircraft productivity only, and changes shown in mission costs are due to increased or decreased productivity for fixed aircraft operating costs per flight hour. Also, the studies do not reflect any aircraft penalties such as increased weight or drag that might be incurred with a given design change.

The original approach in the sensitivity studies was to use one representative mission case for each baseline aircraft for all of the design parameters. The reference mission selected for the small aircraft was a 160-acre (64.8 ha) field with an application rate of 100 lb/acre (112.1 kg/ha), and the large aircraft mission was a 360-acre (145.7 ha) field with application rate of 400 lb/acre (448.3 kg/ha). These missions are representative of the regions of the overall mission spectrum for which each respective aircraft is best suited, based on the mission cost comparisons for the original candidate configurations. Most of the sensitivity data were developed for these missions.

As the studies progressed, it became apparent that the relative effects of a given design parameter might change significantly depending upon the mission being evaluated. As time permitted, an effort was made to examine a range of missions so as to determine the mission-dependent variations in parameter effects. Some of the parameters were thus examined in greater depth than others. Also, the sensitivity analyses were conducted for the baseline configurations existing at the time of each individual study and hence do not all reflect the same aircraft configuration. The specific configuration and mission cases are identified for each set of data.

4.6.2 Ferry Speed

The relative improvement in mission productivity with increased ferry speed is shown in Figure 45 for the small aircraft and in Figure 46 for the large aircraft. A ferry speed of 100 MPH (86.9 kt) was used as the reference point. Three different ferry distance cases were evaluated: field ferry distances of 5 miles (8 km) and 25 miles (40 km) from home base, and load point distance of 25 miles (40 km) from home base with 8 miles (13 km) from load point to the field.

It is seen that increasing ferry speed has a major effect on productivity, even in the case of the short ferry distance. Ferry speed was found to be significant for all missions, but it becomes increasingly important as application rates increase because of the need to reload the aircraft more often for a given area to be treated.

4.6.3 Swath Width

The maximum effective swath width used in the operations analysis model is 1.5 times the aircraft wing span. This is believed to be representative of current aircraft, based on industry contacts and review of the limited literature on the subject. This is a rather arbitrary approach, but there presently are no accepted analytic methods for predicting swath width based on aircraft design characteristics.

In the version of the model used for the present sensitivity study, the mission is flown at maximum swath width if the aircraft has sufficient power to eject the amount of material required and still maintain adequate speed. If the application rate is increased, the aircraft will reduce swath speed commensurate with the added power extraction necessary to eject the grater amount of material. Swath width remains at the maximum allowed value, however, unless the aircraft does not have adequate flight power to

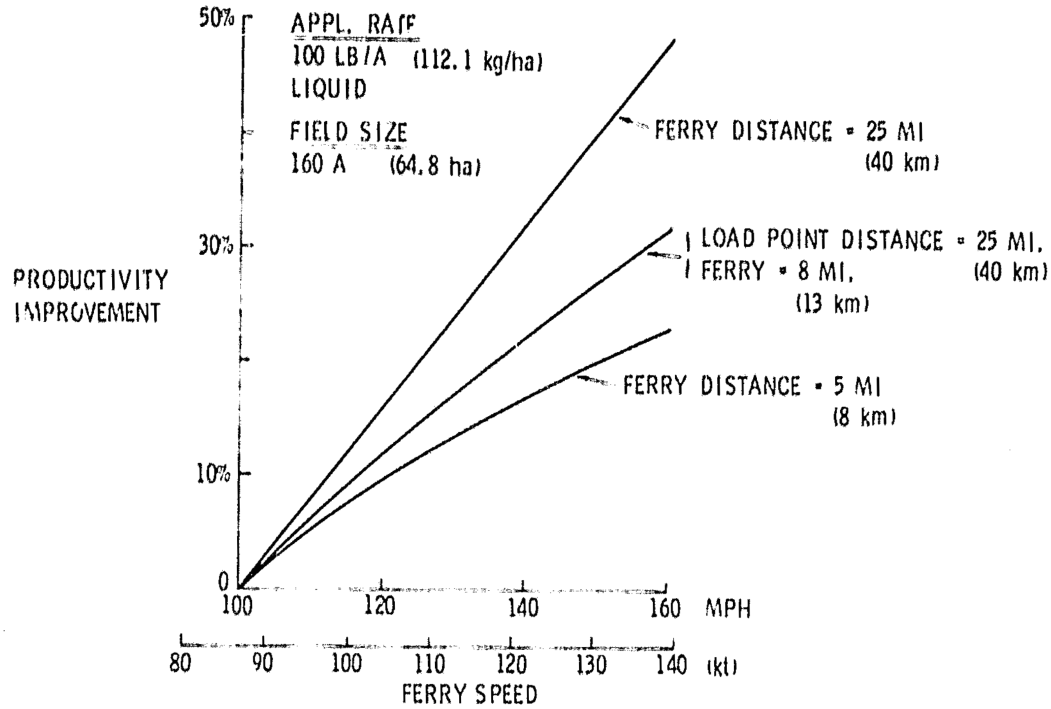


Figure 45. Effects of Ferry Speed (AGB-3-33)

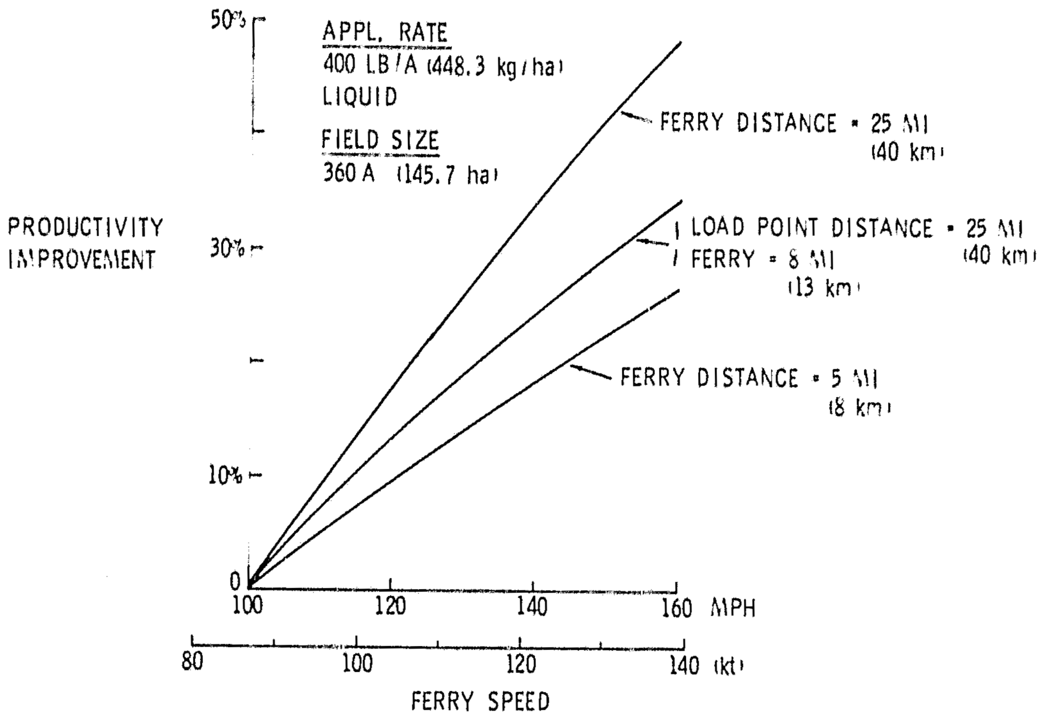


Figure 46. Effects of Ferry Speed (AGB-7-33)

achieve the minimum specified swath speed. In that case, swath width is reduced to that value which allows adequate flight power for minimum acceptable speed.

The maximum swath width for the small baseline aircraft is 82.6 feet (25.2 m) and for the large baseline aircraft is 105.0 feet (32.0 m). The sensitivity study was run by changing the maximum allowed swath width by ±10% and ±20% from the baseline cases. Runs were made over a range of application rates, but all missions were performed at the maximum allowed swath width.

These results are shown in Figure 47 for the small aircraft and Figure 48 for the large aircraft. The data show that the relative effects of swath width vary significantly as the application rate changes. Swath width has a major effect on mission cost for low-application missions but has smaller effect on high-application missions. This is believed to be partly due to the increasing dispersal power required with increased swath width, which at higher application rates causes significant reduction in aircraft working speed. Also, since high-application missions require a greater number of ferry/reload cycles, improvements in swath performance have a smaller relative effect on total mission time.

4.6.4 Structural Weight

Parametric changes in structural weight were made in the model simply by changing the zero payload weight for each of the baseline aircraft. Payload was then changed by the same amount so that aircraft gross weight was held constant. Figure 49 shows the effects on mission cost for a particular mission for each aircraft. The effect of weight reduction is rather significant for these missions.

Figure 50 shows the effects of a 20% reduction in structural weight for a range of application rates in liquid missions. These data show that weight reduction has increasingly significant effects as application rate increases. The reason for this is the fact that a greater number of ferry trips are necessary to reload the aircraft with higher application rates.

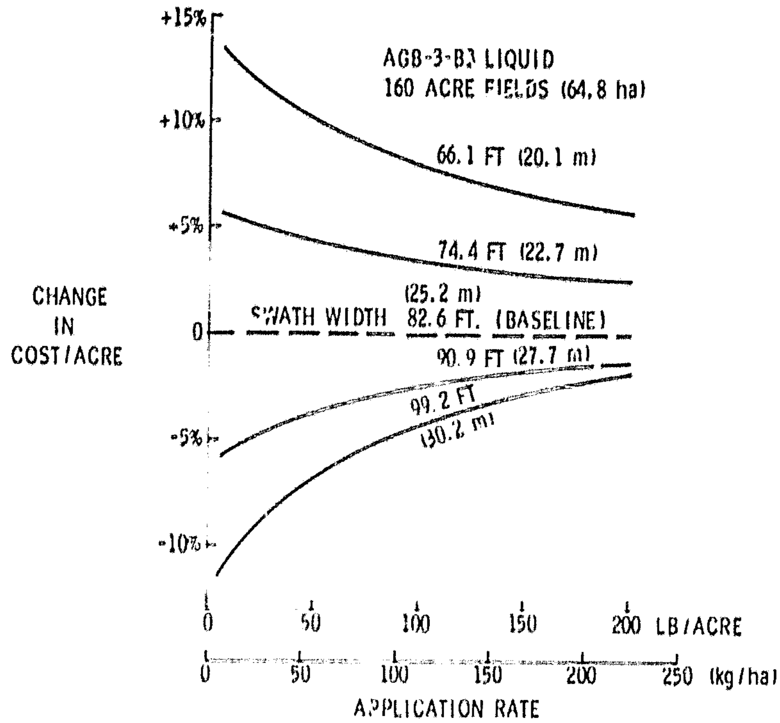


Figure 47. Effects of Swath Width (AGB-3)

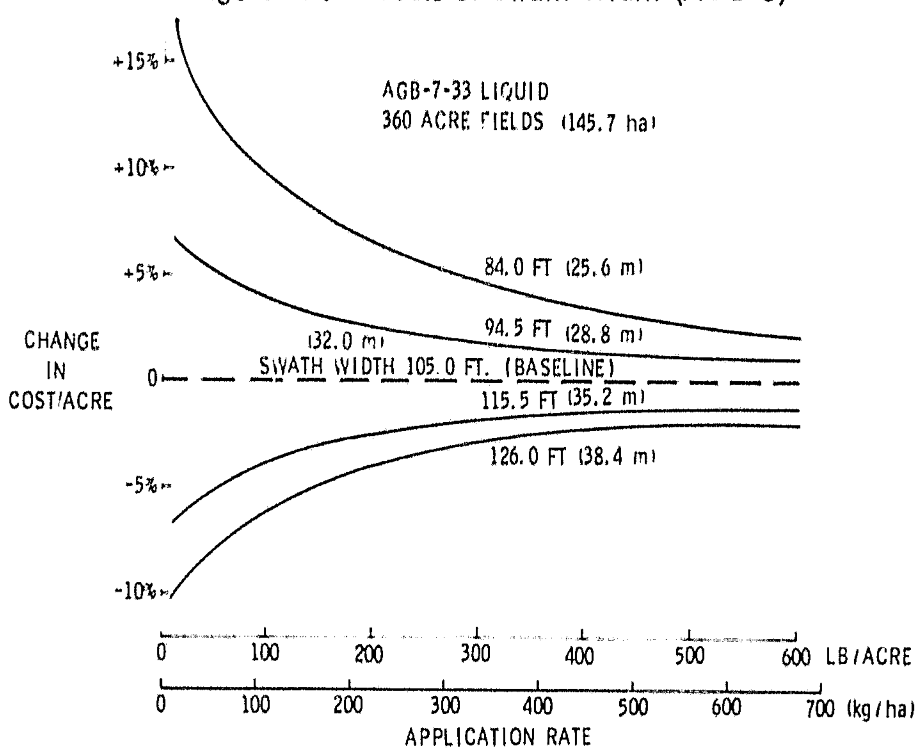


Figure 48. Effects of Swath Width (AGB-7)

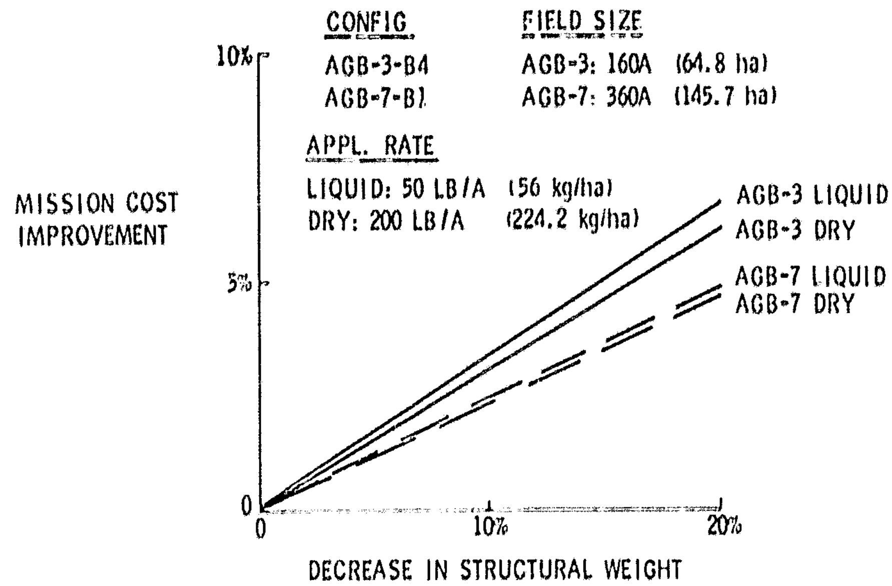


Figure 49. Effects of Structural Weight on Mission Cost

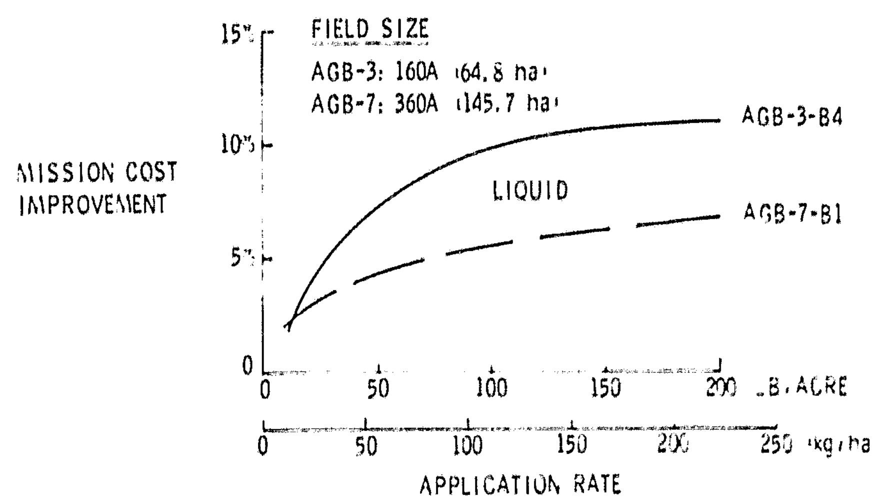


Figure 50. Effects of Structural Weight Reduction

The increase in payload with reduced structural weight has a proportionally greater benefit in reducing these trips for the high-application missions.

4.6.5 Aircraft Drag

The effects of reducing aircraft drag exclusive of the dispersal system are shown in Figure 51 for one particular mission for each aircraft. These effects result from a combination of increased ferry speed, increased swath speed, and some reduction in turn time.

4.6.6 Maximum Lift Coefficient

The effects of increasing maximum lift coefficient are shown in Figure 52 for one particular mission for each aircraft. These effects are due totally to a reduction in average turn time as maximum lift coefficient is increased, as shown in Figure 53. Figure 54 shows the effects of increased maximum lift coefficient over a range of application rates, and it is seen that the relative benefits decline as application rate increases. Figure 55 shows that relative benefits also decline with increasing field size. These relationships are consistent with the effects of turn time in various missions as discussed in the next paragraph.

4.6.7 Turn Time

It is not possible to vary turn time directly in the operations analysis model since this mission parameter is not an input element. Rather, turn time is computed in the model based on aircraft lift, drag, and thrust characteristics and the gross weight of the aircraft at the end of each swath. The model provides as output the maximum and minimum turn times experienced in a given mission.

In order to examine turn-time effects, a number of runs were made with widely varying values of maximum lift coefficient for several different mission cases. Varying lift coefficient caused changes in turn time but had no effect on any other mission performance parameter. Average turn time was then calculated from the output data in each mission case as the

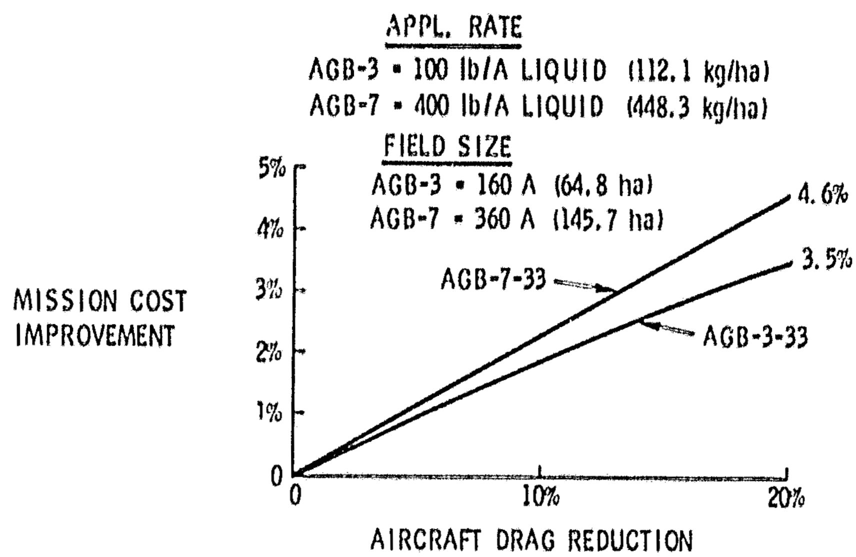


Figure 51. Effects of Aircraft Drag

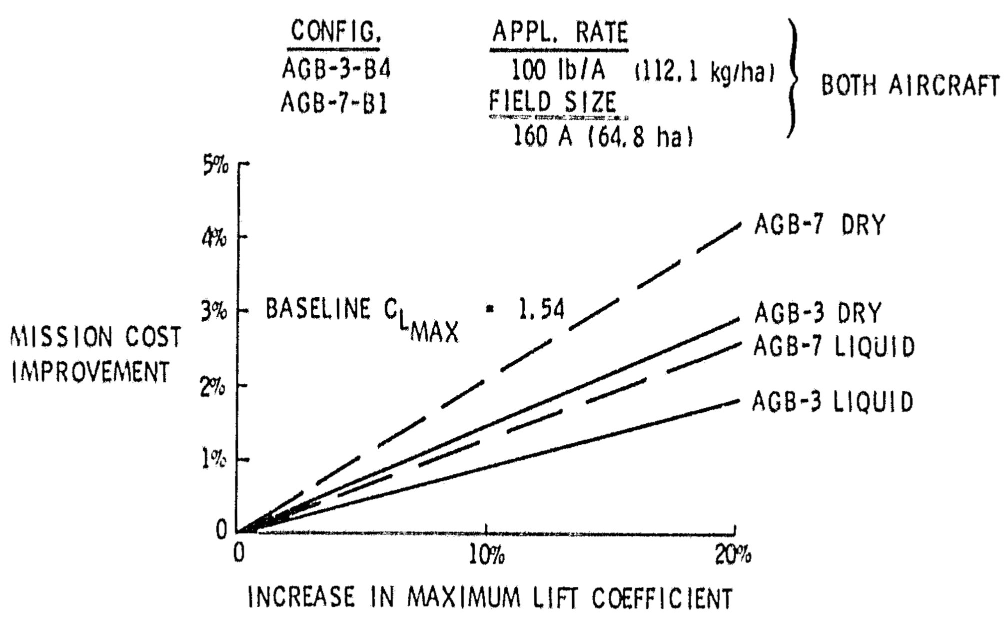


Figure 52. Effects of Maximum Lift Coefficient on Mission Cost

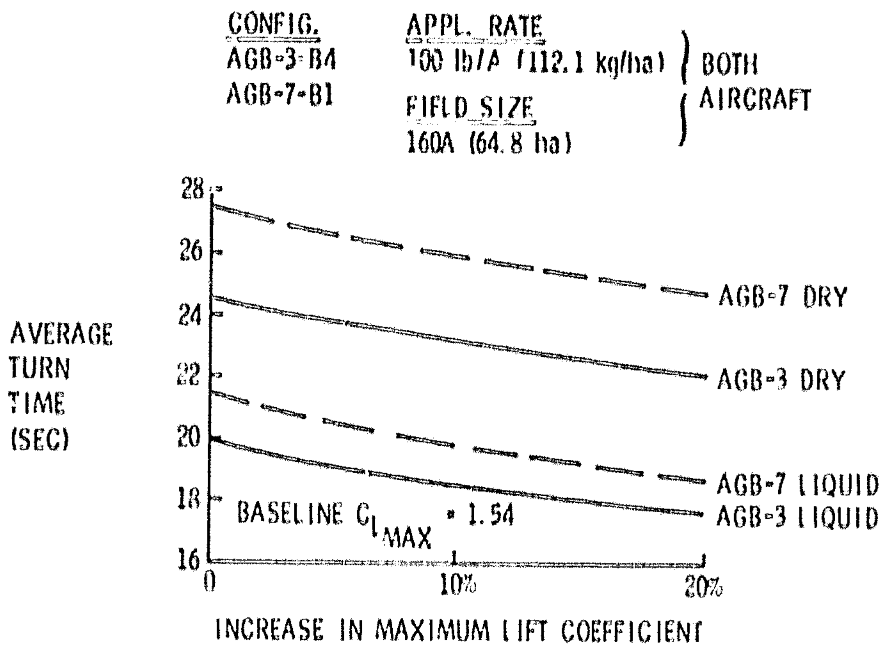


Figure 53. Effects of Maximum Lift Coefficient on Turn Time

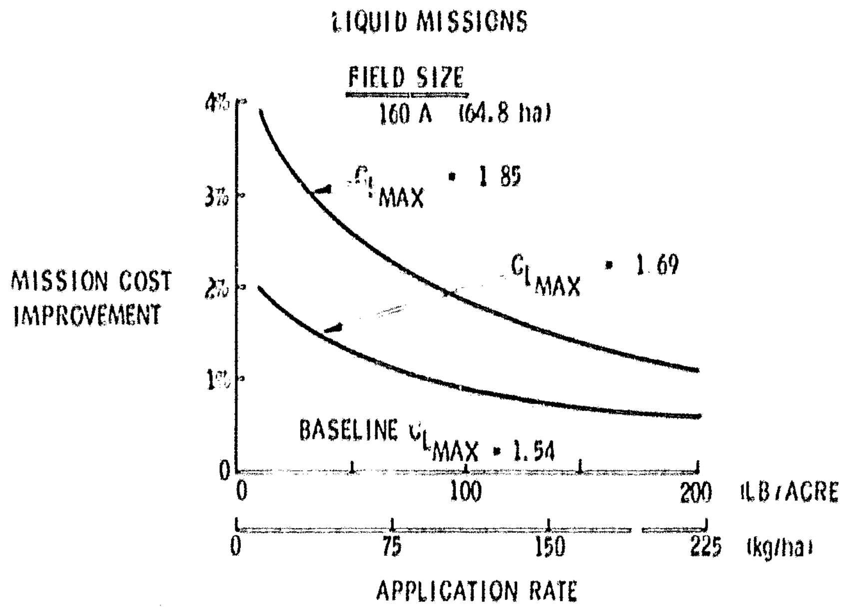


Figure 54. Effects of Maximum Lift Coefficient (AGB-3-B4)

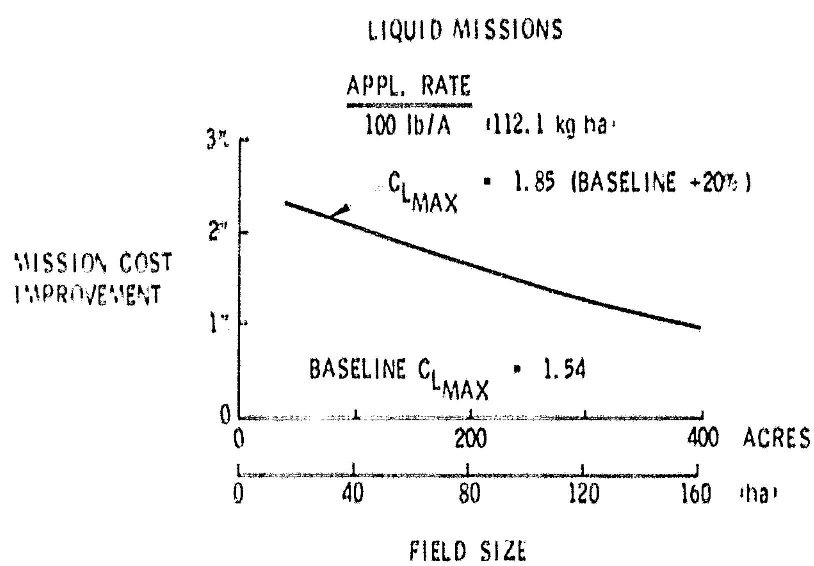


Figure 55. Effects of Maximum Lift Coefficient (AGB-3-B4)

average of the maximum and minimum turn times obtained for that mission. Mission costs were plotted against the average turn time.

Figure 56 shows the turn-time effects for the small aircraft for three different application rates with field size held constant. The darkened data point in each plot is the average turn time for the baseline aircraft in that mission, and the other data points are results obtained by increasing and decreasing the maximum lift coefficient.

The slopes of the three plots are the same. This means that the absolute change in mission cost due to change in turn time is the same in each case. In this set of data, it was found that the cost per acre was reduced by approximately 1¢ for each second reduced from the average turn time. However, relative changes in cost per acre are different in each of the three cases because the costs of performing the three missions are different. That is, the proportion of mission cost due to turns varies with the mission being performed, and turns account for a smaller share of the total cost as application rate increases. The relative importance of turn time thus is pronounced with small application rates but decreases with higher application rates.

Figure 57 shows another set of turn-time data in which application rate is held constant and field size is varied. In this case the three plots have different slopes, meaning that the absolute change in mission cost due to changes in turn time is different in the three cases. For 40-acre (16.2 ha) fields, one second reduction in turn time produced a reduction of approximately 1.8¢ per acre in mission cost; for 160-acre (64.8 ha) fields, the corresponding reduction was .95¢ per acre; and for 360-acre (145.7 ha) fields, .72¢ per acre. Thus, the effects of turn time are most pronounced for small fields, which is consistent with the fact that in small fields a higher proportion of flight time is spent in turns.

In summary, the relative value of reduced turn time is heavily dependent on the mission being performed. Turn time is highly significant with small fields and low application rates but has much less effect with large fields and high application rates.

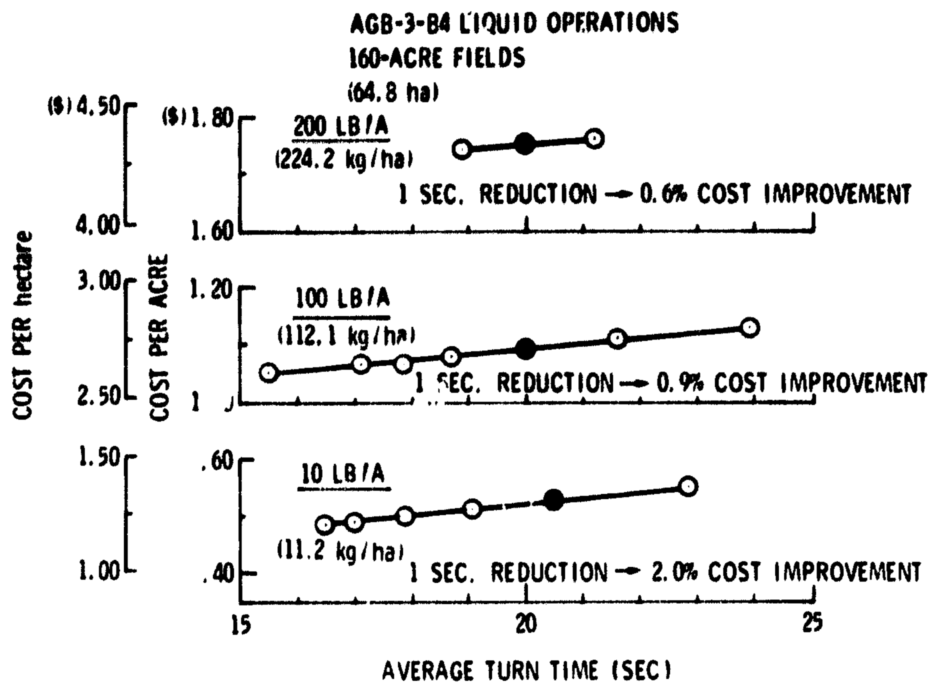


Figure 56. Effects of Turn Time vs. Application Rate

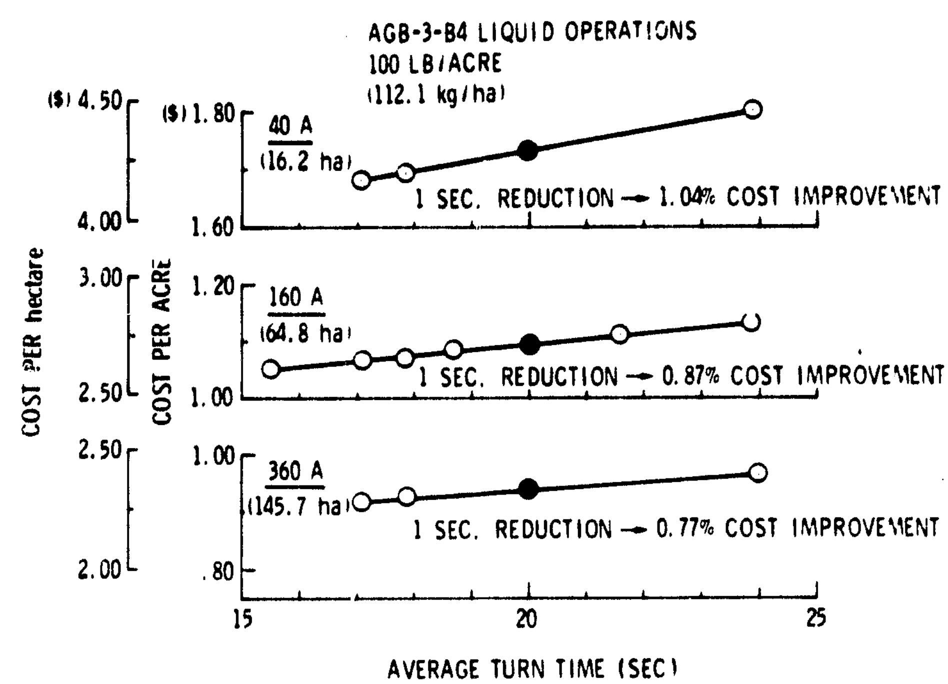


Figure 57. Effects of Turn Time vs. Field Size

4.6.8 Comparison of Parameter Effects

Figures 58 and 59 show the comparative effects of all of the parameters examined in the sensitivity studies for one particular mission case for each baseline aircraft. It must be noted that these relationships will change as missions change, as indicated in the previous paragraphs, so the comparisons must be accepted with caution. These particular cases show structural weight and ferry speed to have the greatest relative effects on mission productivity. Those two parameters decline in relative importance as application rates are reduced from the cases shown.

In conclusion, the effects of various design parameters on mission performance are greatly dependent on the mission. Benefits possible from technology improvements will thus depend on the missions to be performed by the aircraft, and the best design trade-offs for future aircraft will depend strongly on the market the aircraft is intended to serve.

4.7 DISPERSAL SYSTEM CONCEPTS

The performance of the baseline aircraft was determined using dispersal system characteristics that represent current operational systems. One objective of the study was to identify dispersal system concepts that provide capabilities which improve the cost-effectiveness of aerial application operations. The approach to this investigation was to utilize the flexibility of the operations analysis model to determine the potential mission performance improvement that would result from decreases in the drag penalties associated with the operation of the dispersal systems, establish the causes of these drag penalties, and where payoffs were revealed explore alternate designs that could minimize or eliminate the drag penalties.

4.7.1 Liquid Dispersal Systems

4.7.1.1 External Drag - The external drag of the liquid dispersal system was incrementally reduced from its computed value to zero drag. This analysis was conducted under two alternate mission ground-rule conditions:

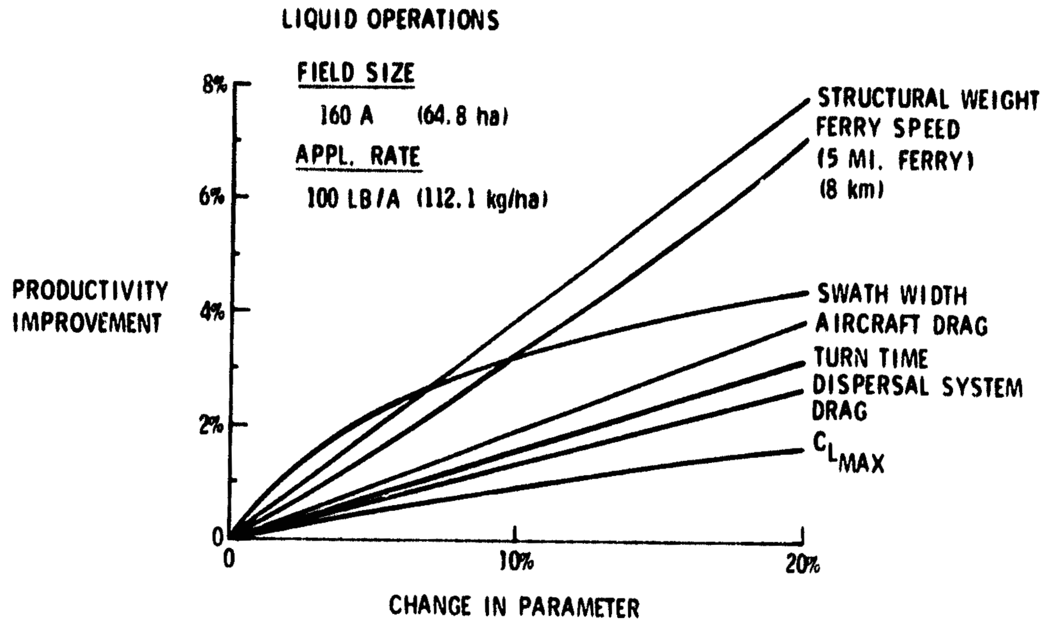


Figure 58. AGB-3 Design Sensitivity Data

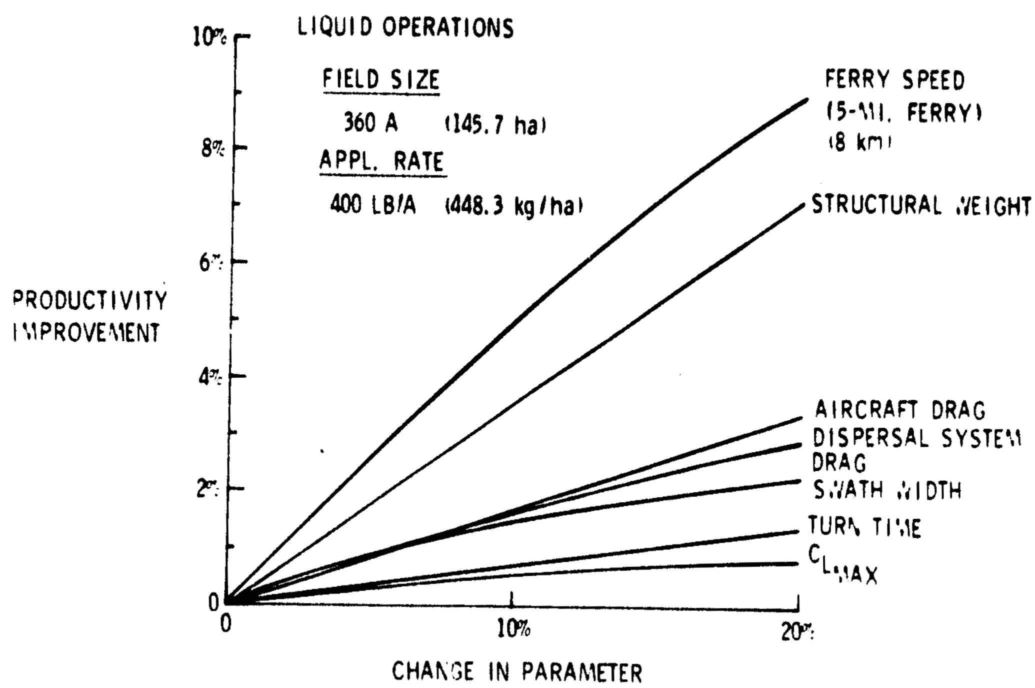


Figure 59. AGB-7 Design Sensitivity Data

(1) use a fixed input value of ferry speed in order to isolate the direct influence of drag reduction on performance during the swath runs, and (2) compute ferry speed and account for the influence of reduced drag on ferry speed and time. The results of this analysis on the AGB-3-B4 aircraft are presented in Figure 60, in terms of percentage improvement in productivity over that of the baseline as a function of drag reduction.

These data show that the effect of a reduction of drag during the swath runs will produce a modest improvement in productivity, up to 2.5% if the external drag could be totally eliminated. However, a major improvement is indicated when the effects on ferry speed are included. The data show a productivity improvement of up to 14% from the combined effects on ferry and swath runs if external drag were completely eliminated.

Figure 61 shows the influence on mission cost of reducing external drag of the liquid dispersal system up to 20% for both the small and large aircraft. The cost improvement for the large aircraft is shown to be considerably greater than that for the small aircraft. This appears to reflect the influence of the much higher application rate used with the large aircraft, which results in more ferry trips between the fields and load points. The effect of drag reduction on ferry speed would produce greater benefits in high-application missions.

It is apparent from these results that external drag of the liquid dispersal system has a significant effect on mission productivity and cost, due primarily to effects on ferry speed. Comparing the cost improvements in Figure 61 with those given previously in Figure 51, it is seen that a 20% reduction in dispersal system drag produces almost the same benefit as a 20% reduction in total aircraft drag (excluding dispersal system). A drag reduction of 20% for existing liquid dispersal systems is considered feasible with close attention to fairing design, component location, and interference effects.

The parasite drag of the external components of conventional liquid dispersal systems is attributed to three main sources: form and interference drag of the externally mounted liquid pump and associated plumbing; the spanwise boom and support brackets; and the spray nozzles.

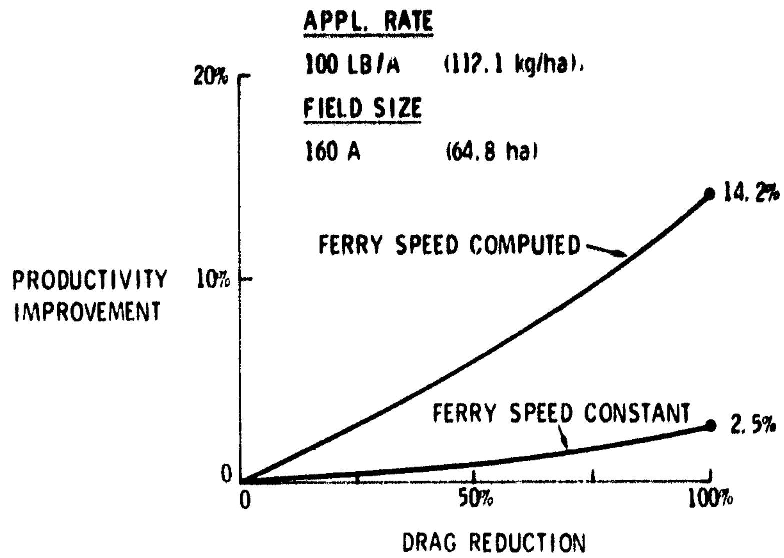


Figure 60. Effects of Liquid Dispersal System Drag (AGB-3-33)

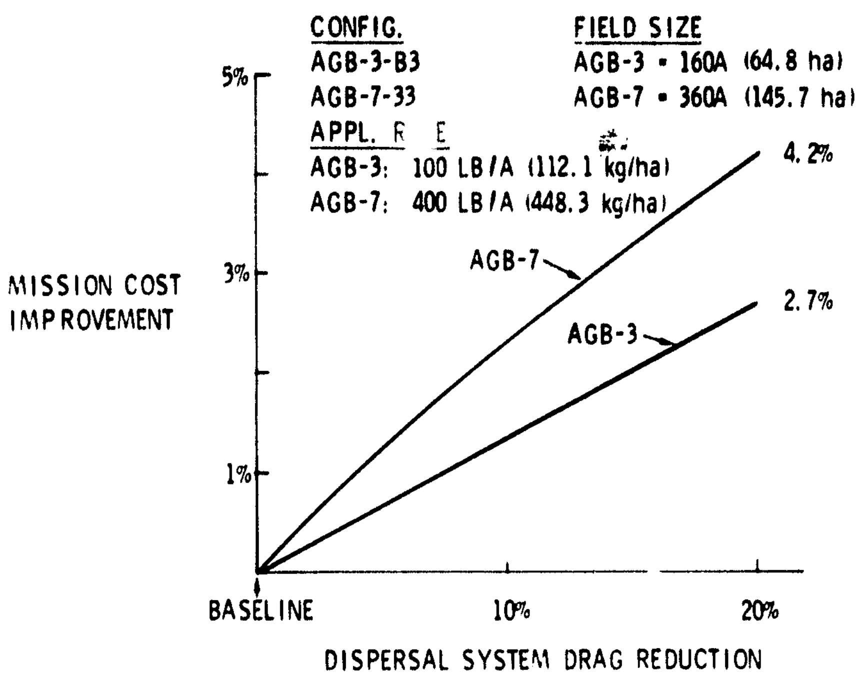


Figure 61. Effects of Liquid Dispersal System Drag

The current state-of-the-art in nozzle design results in a partial dependence on the orientation of the nozzle relative to the freestream around the aircraft to determine the droplet size of the material being applied. Since nozzle design was excluded from consideration by the NASA guidelines for this study, no concepts for reducing nozzle drag have been considered. However, it is recognized that nozzle designs which would permit the longitudinal axis to always be oriented parallel to the freestream would permit the nozzle drag to be reduced below the levels currently encountered.

Pump and plumbing drag can be markedly reduced or eliminated by carefully designed fairings or by mounting these components internal to the aircraft. Maintenance accessibility has been frequently stated by operators as a primary reason for lack of support for these approaches, but there is clearly a tradeoff between maintenance costs and operational costs that can be made to establish the value of low-drag pump and plumbing installations. Such a tradeoff is appropriate for additional study efforts.

Spray boom drag can potentially be eliminated by enclosing the boom within the wing contours. This approach has been abandoned in the past because of corrosion problems created from the inevitable leaks that develop in the liquid system. One concept which appears to merit further development, however, is to utilize the component of the wing that is inherently external to the primary wing structure, the trailing edge flap. The flap could house the spray boom, or the spray boom could be formed as an integral part of the flap structure. Figure 62 illustrates a flap design in which a circular tube located at the hinge line of a simple flap supports the flap hinge bearings. In this approach the flap would be fabricated of a corrosion resistant material and be installed in a manner that would permit rapid removal from the aircraft and easy disassembly for inspection.

Another configuration that could eliminate boom drag is illustrated in Figure 63. In this arrangement the boom forms the trailing edge of the flap. The boom is attached to the flap skins by continuous hinge pin sections extending along the full span of the flap. This configuration would be particularly appropriate for aircraft with full span flaps.

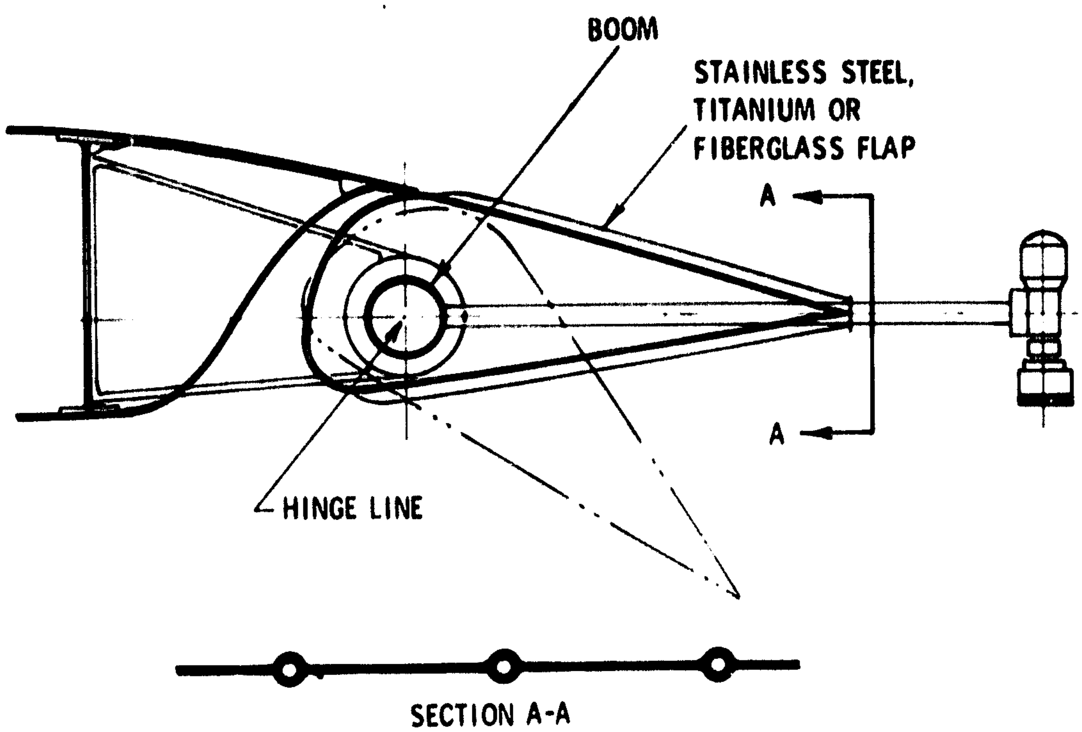


Figure 62. Flap/Boom Arrangement

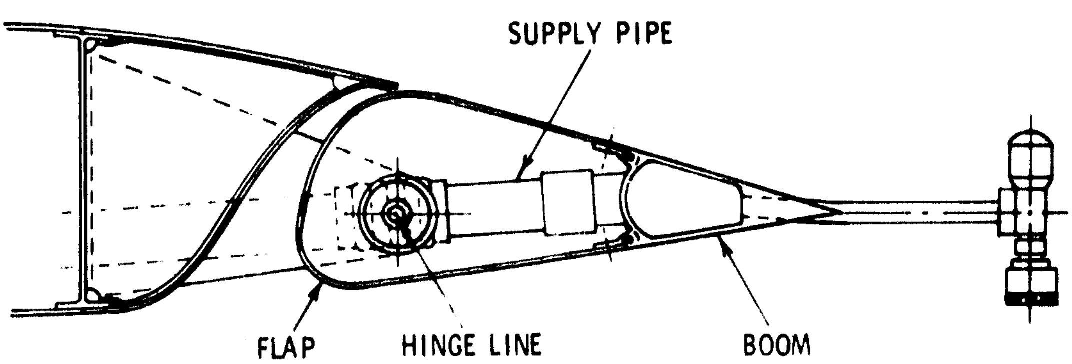


Figure 63. Trailing Edge Boom

The parasite drag coefficient computed for the liquid dispersal system of the AGB-3-B4 configuration, referenced to wing area, is .027, of which approximately 6% is due to pump and plumbing drag and 80% is due to boom, brackets and interference. If these items were enclosed, a liquid dispersal system parasite drag reduction of the order of 86% would appear possible. A reduction of this amount would provide a mission productivity increase of 10% to 11%.

4.7.1.2 Pumping Drag - As described in Section 3.5.1, a second penalty associated with the liquid dispersal systems is the additive drag created by the extraction of power from the system to pump the liquid from the hopper through the nozzles. The level of power extracted reflects three major liquid system parameters: the hydraulic power contained in the fluid flow, the efficiency of the pump transferring the energy into the fluid, and the efficiency of the drive mechanism converting the power from the energy source to the fluid pump.

An analysis was conducted to establish the influence of the combined efficiency of the pump and pump drive, termed Pumping Efficiency, on the productivity of the total application system. The pumping efficiency was varied over a range from 3% to 50% for the small and large aircraft, and the resulting variation in productivity is presented in Figure 64. These results show a sharp knee in the productivity curve in the range of pumping efficiency from 5% to 15%, with improvements in pumping efficiency above 15% producing an insignificant improvement in mission productivity. Corresponding effects on mission cost are shown in Figure 65.

The steep portion of the productivity curve below the knee occurs in a region where a small incremental increase in efficiency produces a large absolute decrease in power extracted by the pumping system. The large amount of additional power available allows a sharp increase in swath speed and/or swath width, depending upon the particular mission conditions, and there is a corresponding jump in mission productivity. As efficiency continues to increase, however, the absolute change in power extraction declines rapidly, and the effect on productivity becomes increasingly small. The pattern of change in power extraction is illustrated in Figure

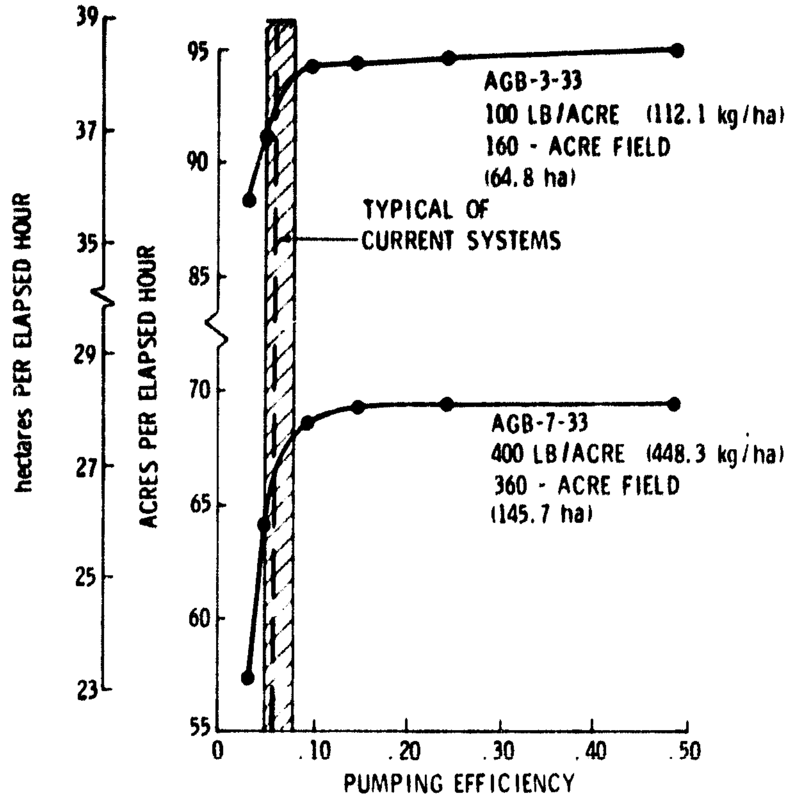


Figure 64. Liquid System Pumping Efficiency

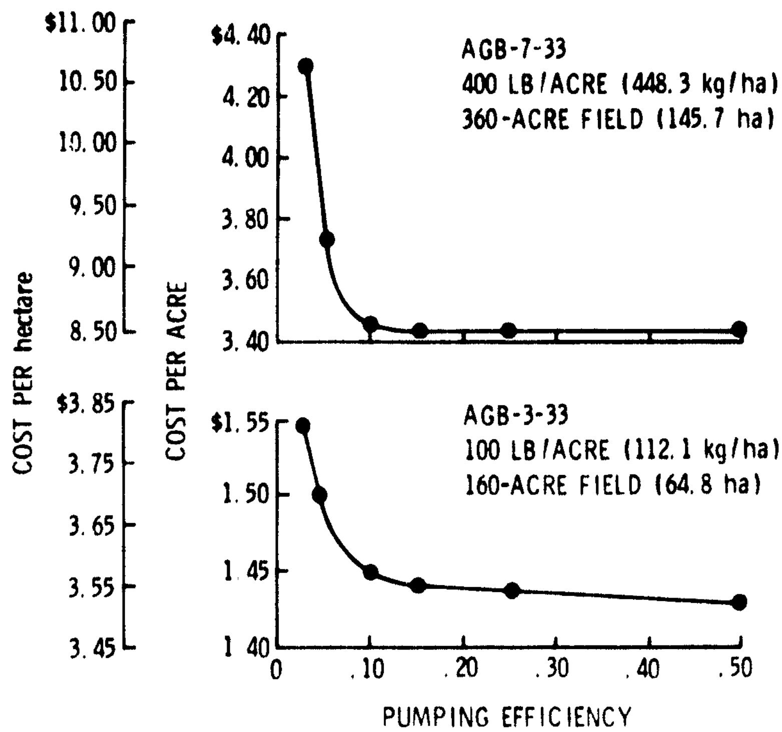


Figure 65. Effects of Pumping Efficiency on Mission Cost

66 for the small aircraft in the same mission used in the productivity and cost analysis.

Additional cases were investigated over a range of application rates, and it was found that the knee in the productivity curve moves to lower values of pumping efficiency as the application rate decreases. This behavior reflects the reduction in hydraulic power required by the liquid material fluid flow. At low fluid-flow rates, the hydraulic power is small, and even low pumping efficiencies do not impose a serious additive drag on the aircraft. As the flow rate increases with higher application rates, the hydraulic power requirement becomes increasingly severe. Small changes in efficiency then represent large absolute changes in power extracted from the system.

From data presented in available literature, such as reference 23, overall pumping efficiencies of typical agricultural aircraft installations fall in the range from 5% to 8%. This range is indicated by a band in Figure 62. In the range of application rates typical of current liquid systems, less than 50 lb/acre (56 kg/ha), the knee of the curve is at or below the efficiency level of typical current systems. This is consistent with current operator opinion, where the difference in aircraft performance with the liquid pump system operating or not operating is considered to be of small significance. As liquid application rates increase, however, it becomes increasingly more important to provide pumping efficiencies of at least 10% to 15%.

Figure 67 shows pumping system power extraction for the refined baseline aircraft over the entire range of application rates specified for the present study. These data are based on constant 10% pumping efficiency. The point identified on each curve as "maximum swath width" represents the highest application rate that can be achieved at full swath width of 1.5 times aircraft wing span. Beyond that point the swath width must be progressively reduced to maintain adequate power for flight. This is due to the increasing pumping power required as the application rate increases.

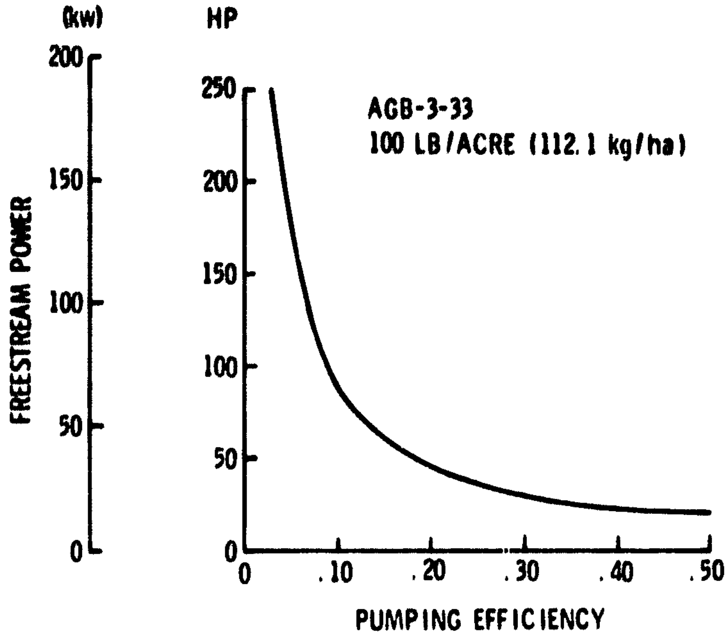


Figure 66. Power Extracted Versus Pumping Efficiency

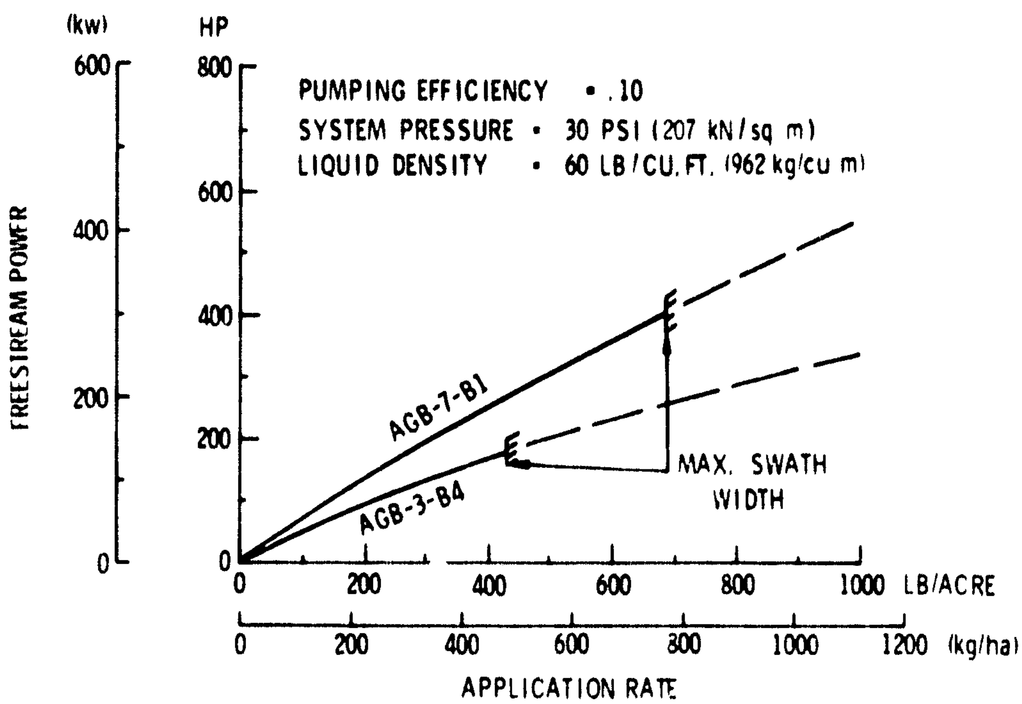


Figure 67. Pumping System Power Extraction

4.7.2 Dry Material Dispersal Systems

The dry material dispersal performance of the baseline aircraft is based upon empirically determined capabilities of conventional dry material spreaders, as described in Section 3.5.2. These systems contribute a significant drag penalty to the aircraft, which results in reducing productivity and increasing mission costs. In order to better understand the sources of this drag an analysis of one typical spreader design was conducted.

4.7.2.1 Conventional Spreaders - The analysis of drag characteristics of conventional spreaders is based on a typical ram-air spreader tested by the Ohio Agricultural Experiment Station. The overall test program, reported in reference 15, included wind tunnel tests with a variable - geometry distributor section and flight tests with a complete spreader. The wind tunnel tests included measurements of air inlet velocity and material exit velocity for wheat over a range of material flow rates. These data, coupled with dimensional details provided for the flight test spreader, permit an engineering analysis of both external and internal drag of the complete spreader.

The spreader is illustrated in Figure 68. It was tested on an 85-horsepower (63 kw) Piper J-3 aircraft. The spreader was mounted on a chute below the hopper gate four inches (.10 m) below the bottom of the fuselage, which is typical of dry-spreader installations in current use.

An analysis was first made of spreader drag for the condition in which no material is being released into the spreader. Estimated drag build-up from the analysis is shown in Figure 69 as a function of flight speed. The results indicate two primary contributors to spreader drag: (1) flat plate and base drag, and (2) internal flow drag.

Flat plate and base drag are estimated to account for approximately half of the total spreader drag. The flat plate drag is created by the four-inch (.10 m) exposed chute connecting the spreader to the hopper. The base drag is created by the unvented regions between the channel discharge areas and

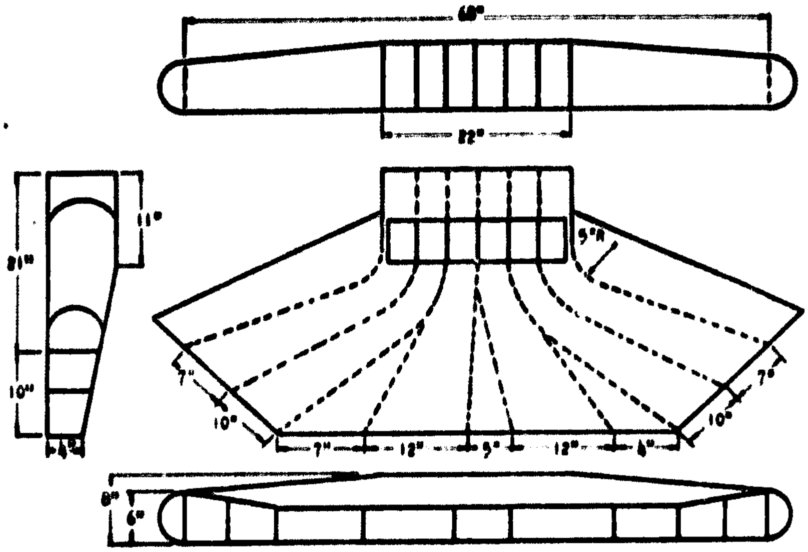


Figure 68. Ohio Agricultural Experimental Station Dry Material Distributor

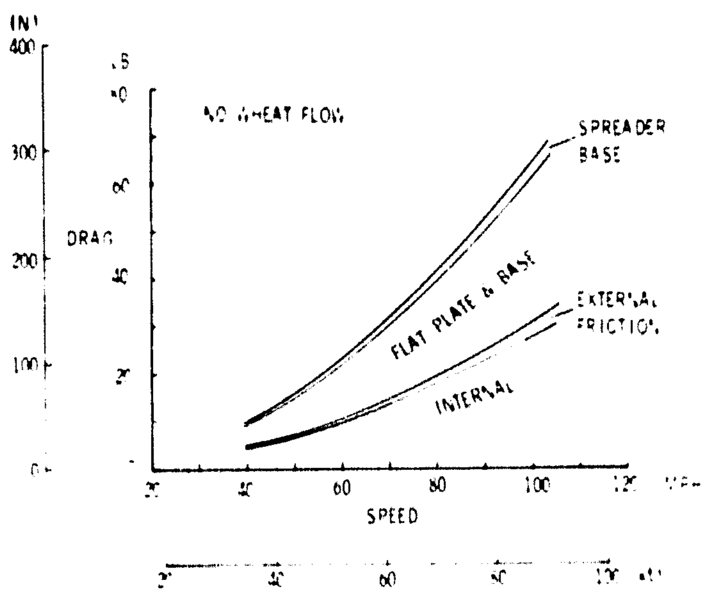


Figure 69. Ohio Experimental Distributor Performance Characteristics

by the projected area of the downward-sloping rear top surface of the spreader directly behind the chute. Much of this drag could be eliminated with a spreader design that: (1) allows the spreader to be mounted flush against the fuselage without the exposed chute; and (2) provides the tapered cross-section by an upward-sloping bottom surface in lieu of the downward sloping upper surface. It was not possible in the present study, however, to evaluate the effects on swath pattern of ejecting material along the bottom of the fuselage with this type of spreader design.

The second major contributor to spreader drag is energy loss in internal flow through the spreader. Each internal channel was analyzed by a flow balance technique, based on duct geometry, to obtain an estimate of these energy losses. The basic drag equation used in the analysis is as follows:

$$D = \frac{W_a}{g}(V_i - V_e \cos \theta)$$

where D = internal drag (pounds)

W_a = air flow (pounds/sec)

V_i = inlet velocity (feet/sec)

V_e = exit velocity (feet/sec)

θ = exit angle relative to frestream

g = gravity constant (feet/sec^2)

For the case where there is no material being injected into the spreader, the analysis shows that the four outer channels produce 91% of the total internal drag. This is due primarily to the large momentum losses that occur in turning the flow to a large exit angle (θ) through an expanding corner duct. Even if the turning losses were minimized by carefully designed duct corners, the large angle of the exit flow relative to the freestream would prevent recovery of most of the inlet flow momentum.

Further analysis was conducted to determine the approximate effects on drag of introducing material into the spreader. The wind tunnel test results for wheat from reference 15 show that the introduction of material causes a reduction in inlet velocity (V_i) and exit velocity (V_e), and there is a corresponding reduction in air flow (W_a). The specific effects will vary with the geometry of the individual channels, the material flow rate, and airspeed. The analysis was performed for each channel at an airspeed of 100 MPH (87 kt) over a range of material flow rates.

In the case of the high-loss outer ducts, the analysis shows that internal drag actually decreases when material is introduced. The dominant effect of material injection in this case is a reduction in air flow due to blockage in the channel. With reduced flow there is less momentum loss penalty, and internal drag is reduced. Internal drag contiues to decrease in these ducts as material flow rate increases. At the same time, there is an increase in additive spillage drag at the duct inlets, but the additive drag is not sufficiently large to off-set the internal drag reduction.

Injection of material into the low-loss inner ducts causes internal drag to increase. Initial drag was quite low in this case, and the effect of the material on internal pressure loss is the dominant factor. Drag continues to increase in these ducts as material flow rate increases. This drag increase combines with the additive spillage drag at the outer ducts to approximately balance the internal drag reduction in the outer ducts. The net effect is to produce virtually no change in total spreader drag over a wide range of material flow rates. This result is consistent with repeated operator comments that opening or closing the hopper gate with a dry-material spreader has no apparent effect on aircraft performance.

Figure 70 shows the results of the analysis in terms of total spreader drag, both internal and external, as a function of material (wheat) flow rate from 0 to 1000 pounds per minute (0 to 454 kg/min).

Material flow tests reported in reference 15 indicate that the maximum material velocity achieved at the exit of test ducts was 25% of the air inlet velocity, and this occurred at a weight flow ratio, weight of

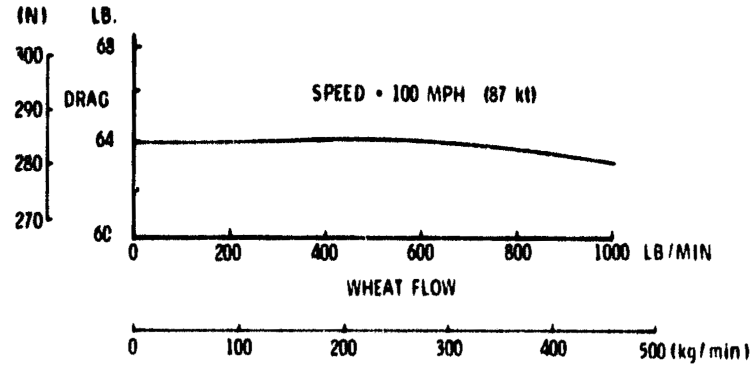


Figure 70. Distributor Drag Versus Flow Rate

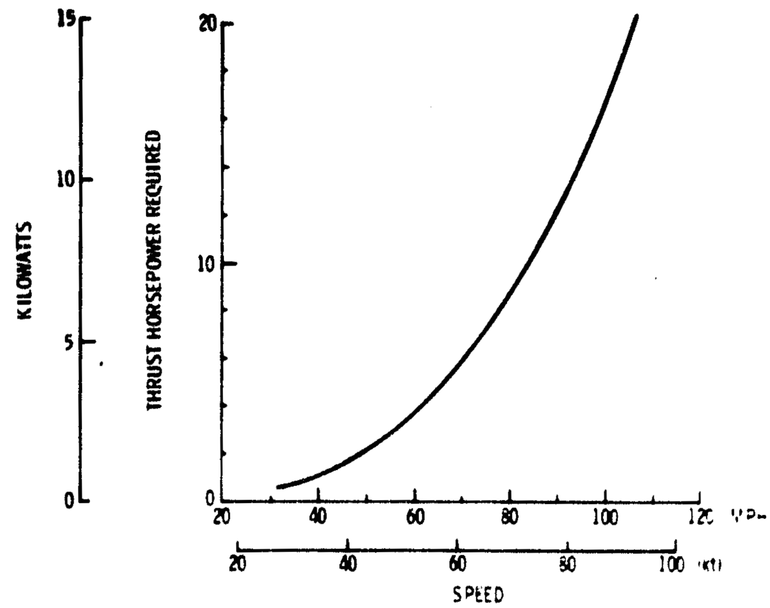


Figure 71. Estimated Distributor Performance

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material to weight of air per second, of approximately 1.0. Based upon these data the efficiency of the ram air spreader, in terms of the ratio of the horsepower represented by the material mass flow leaving the spreader to the thrust horsepower represented by the internal drag of the spreader, is about 8%. The ram-air spreader, therefore, represents a poor mechanism with which to impart a lateral velocity to material being dispersed by an aircraft. The estimated thrust horsepower extracted from the J-3 aircraft by this spreader is indicated in Figure 71.

Other concepts appear feasible for accomplishing the basic objective of the dry material spreader, which is to physically move the material laterally as far as possible from the aircraft centerline while maintaining an even coverage across the width of the swath. These concepts include: simple free release of the material from one or more openings in the bottom of the aircraft and allow aerodynamic interaction to spread the material; physical transport of the material laterally through the aircraft wing structure for release at outboard locations; release from multiple hoppers located laterally along the aircraft wing; and mechanical devices to induce lateral velocity to the material at one or more locations on the aircraft.

4.7.2.2 Free Release Technique - The method of simply allowing the material to flow at a controlled rate out of openings in the bottom of the aircraft represents an attractive approach because it creates essentially no additional drag on the aircraft, imposes the lowest weight penalty, requires the simplest and therefore the most reliable gating mechanism, and should be the least expensive. This technique is widely used in New Zealand for top dressing application, and has received some analytical and experimental attention there. Some of this work is reported in references 24 and 25.

Small scale tests and full scale application data were corrolated by Lee and Stepheson (reference 24) to develop a relationship between the effective width and shape of the swath resulting from a free release of dry material and the flow rate of the released material. The swath spread cross-section produced by a free material release through a circular hole is approximately gaussian in form. At flow rates above approximately 10 pounds/sec (4.5 kg/sec) a consistent relationship between spread and mass flow was found that can be satisfied by the expression,

$$SD = KM^n$$

where SD is the standard deviation, M mass flow rate, and K and n are constants for particular flight speed. At flight speeds near 200 feet/second (61 m/sec) the value of $K = 2.9$ and $n = .237$.

Examination of the shape of the swath spread cross-section produced by the free material release method shows that the lateral distance from the centerline of the swath to the point where the overlap of the adjacent swath would combine to produce a relatively smooth coverage is approximately twice the standard deviation dimension computed by the equation. The swath width produced by the free release method of dispersal is therefore approximately:

$$SW = 4 \times SD$$

where SW = swath width

or,

$$SW = 11.6 \times M^{.237}$$

at flight speeds in the regions of 200 ft/sec (61 m/sec).

Because material mass flow rate is directly related to coverage, in terms of pounds per acre and swath speed, mission productivity and cost of aircraft using the free release method could be investigated by the operations analysis model. Figure 72 presents the relationship between application rate and swath width for several swath speeds. Also shown on this figure for reference is the relationship of application rate and swath width produced by the conventional spreaders used on the baseline aircraft. The implications of these relationships is that the current spreaders should provide superior productivity below approximately 300 pound/acre (336.2 kg/ha) rates, and the free release method should be superior at higher rates. However, because the free release method achieves the indicated swath widths at no additional drag penalty to the aircraft, the cross over might occur at lower aplication rates.

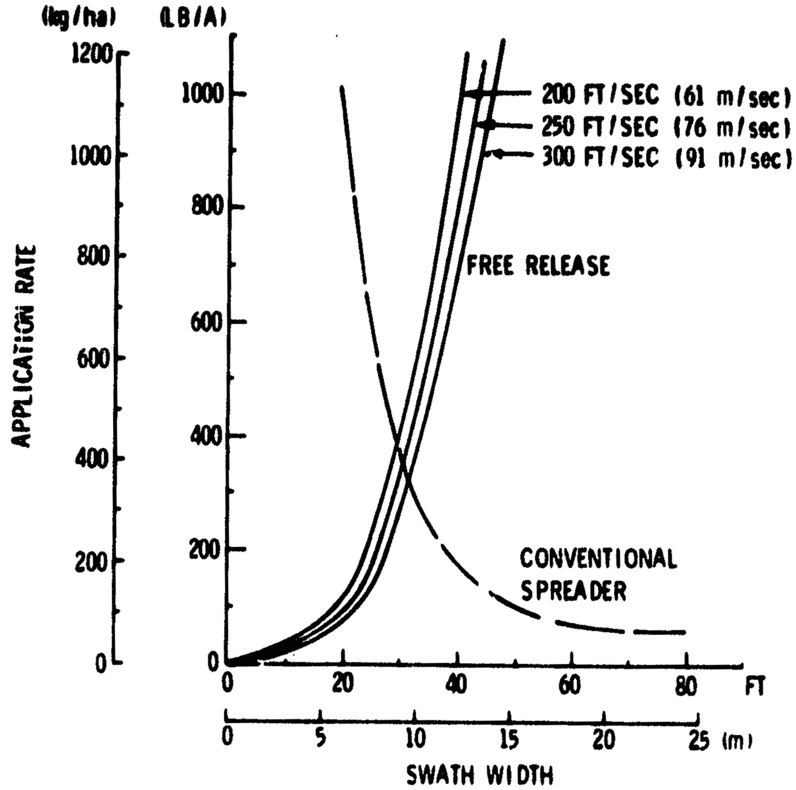

Figure 72. Dry Material Swath Width vs. Application Rate

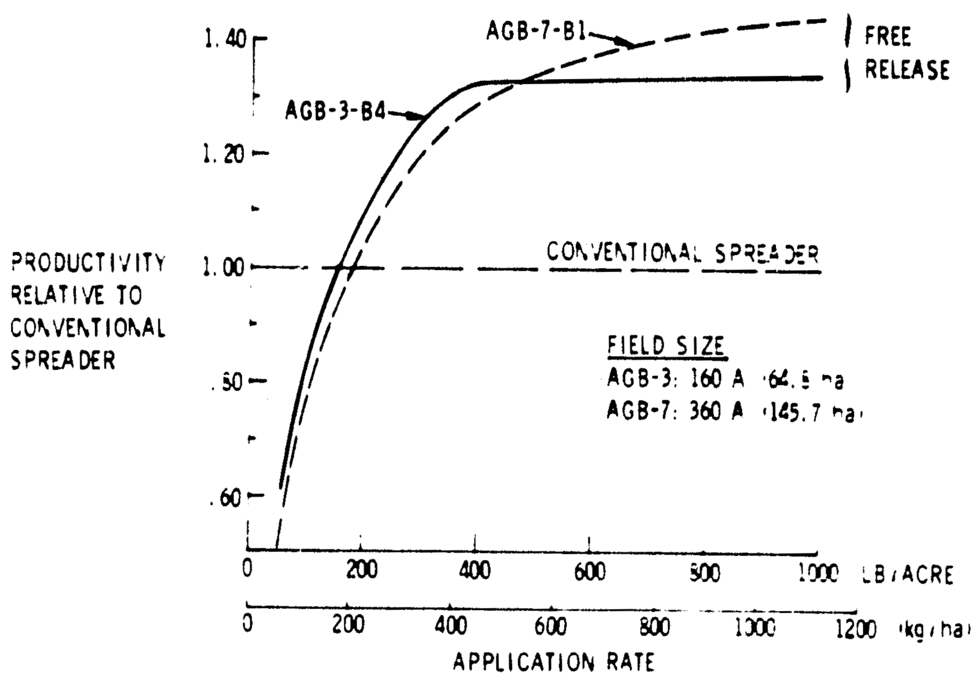

Figure 73. Mission Productivity with Free Release of Dry Material

Both the AGB-3-B4 and AGB-7-B1 baseline aircraft were analyzed using an operations analysis model modified to represent the free release swath width characteristics. These data are presented in Figure 73 to show productivity of the free release method relative to that of the conventional spreader, and in Figure 74 to show mission cost relative to that of the conventional spreader.

In Figure 73 the effect of the rapid decrease in swath width with low application rate for the free release method is apparent by the rapid decrease in productivity below application rates of 150 to 200 lbs/acre (168 to 224 kg/ha), for both large and small aircraft. Above this point, however, the productivity increases significantly above that of the conventional spreader. The data in Figure 74 indicate that the cross-over in mission cost occurs at approximately the same value of application rate as did the cross-over in productivity. The free release method appears to provide a clear cost advantage for both aircraft above application rates of 150-200 lbs/acre (168-224 kg/ha).

The validity of these results is dependent upon the extent to which the swath spread cross section will actually follow the characteristics employed in the analysis. Because the potential payoff for dry material application rates above 150 to 200 lbs/acre appears high, further experimental verification of these characteristics should be undertaken.

4.7.2.3 Multiple Release Points - Swath width can be increased by dispensing dry materials at more than one location laterally along the span of the aircraft wing. This is analogous to using multiple nozzles along the boom of a liquid dispersal system. Multiple release points can be provided by transporting the dry material outboard through the wing from a central hopper, releasing the material from multiple hoppers located along the wing, or combinations of these methods. Release at each point can be through the free release method, through conventional dry spreaders, or through mechanical spreaders.

Investigations were conducted to determine the effect on dry dispersal mission performance of multiple release points for both the free release

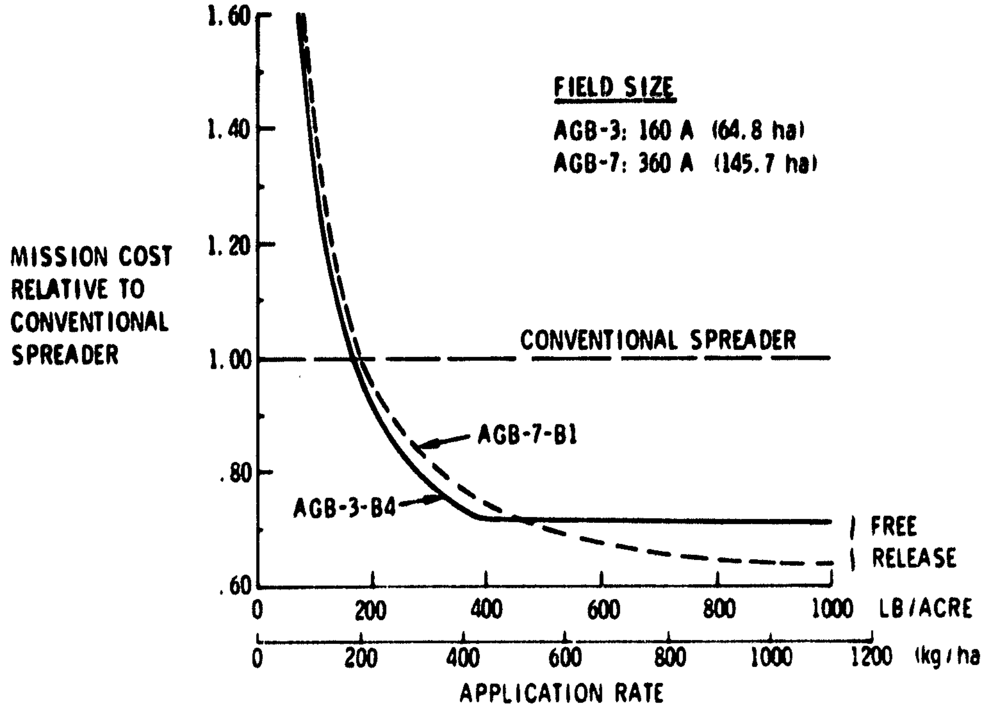

Figure 74. Mission Cost with Free Release of Dry Material

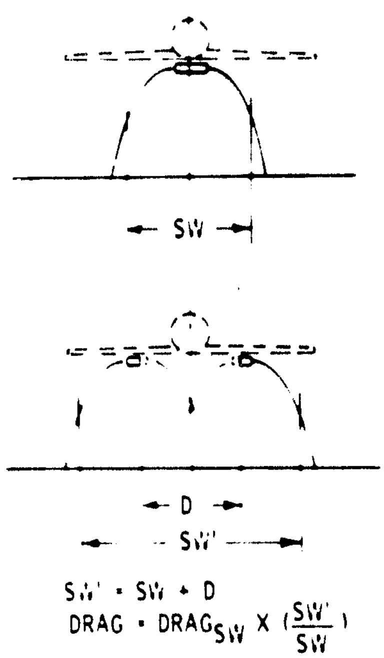

Figure 75. Conventional Spreader with Separation

method and conventional spreaders, using modified operations analysis models. For the free release case swath width was assumed to increase directly with the separation distance between outermost release points, with no increase in drag.

The method used to account for separation distance between conventional spreaders is illustrated in Figure 75. The swath width for the conventional spreader was assumed to increase directly with the separation distance; however, spreader drag was also increased by the ratio of the total swath width to the basic swath width. This drag increase accounts for additional sections added to the spreaders to provide the overlap of material in the gap created by separating the basic spreader.

The results of the mission analyses for the free release method are presented in Figure 76. Mission cost for both aircraft continues to decrease with separation distance out to the maximum separation considered, aircraft wingspan. For the small airplane the cost/acre at a separation distance of 55 feet (17 m) is approximately 60% of that at zero separation. For the large airplane the cost/acre at 70 feet (21 m) separation is approximately 75% of that with no separation.

The effect of separation on conventional spreaders is significantly different from that of the free release method due to the increase in drag associated with the added spreader sections. Figure 77 shows that separation has little effect on the small airplane mission cost, reducing the cost/acre very slightly up to approximately 30 feet (9 m) and increasing the cost/acre slightly at greater separations. The cost/acre is reduced slightly for the large airplane over a separation distance of only about 10 feet (3 m) and rises rapidly above that distance. The more rapid increase in cost/acre for the large aircraft reflects the adverse influence of the increased drag on the ferry speed and time, which decrease productivity more rapidly with increasing application rate.

This investigation indicates that dispersal system concepts incorporating the free release method can benefit significantly by providing multiple dispersal points along the wing, provided the technique can be developed to

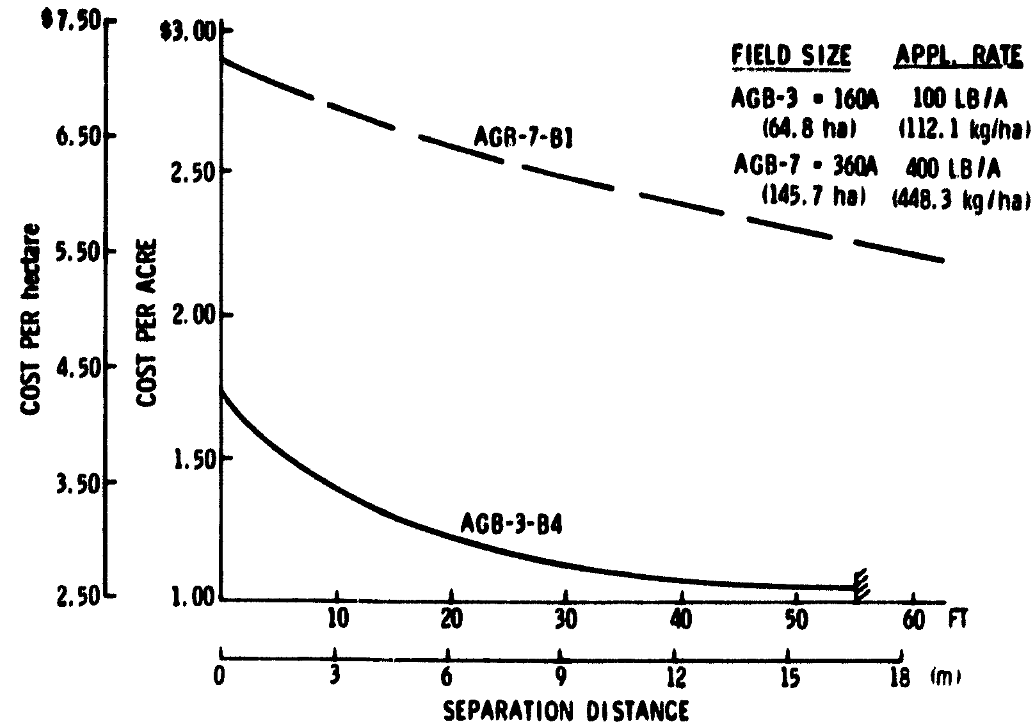

Figure 76. Effect of Dispersal Point Separation Distance with Free Release of Dry Material

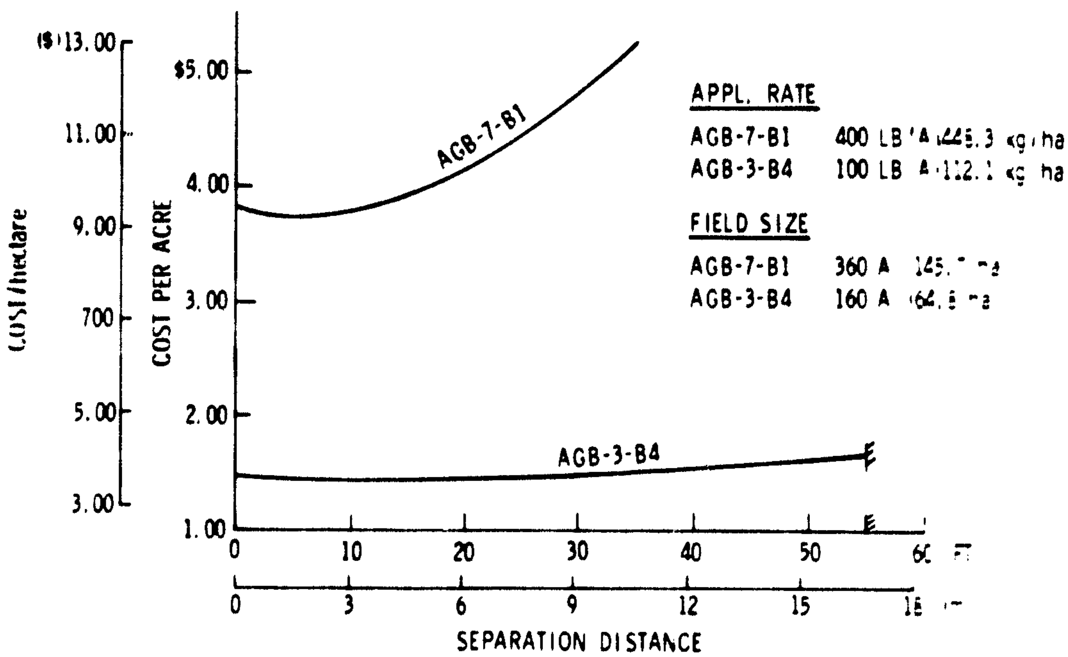

Figure 77. Effect of Dispersal Point Separation Distance with Conventional Dry Spreaders

provide a smooth swath spread cross-section. The investigation also shows that multiple dry material spreaders similar to those now in use, although not necessarily symmetrical, can be employed with very slight advantage up to modest separation distances, less than 30 feet (9 m).

The power required to transport the dry material laterally through the wing of the aircraft has not been accounted for in the analysis. It appears that these power requirements can be relatively small, however, by using mechanical systems such as screw conveyors. Also, no weight penalties were assessed to the transport system. For those cases where multiple release points require the use of transport mechanisms, the weight and power requirement of these systems will reduce to some extent the benefits of the approach. Incorporation of these factors in the analyses, although beyond the scope of this study, should be the subject of further investigations.

4.7.2.4 Mechanical Spreaders - Another method of increasing dry material swath width is to mechanically accelerate the material particles to a lateral velocity. Two mechanical spreaders that have been developed include a rotary disk revolving about a vertical axis and a rotary drum revolving about a horizontal axis. Inadequate data are available to permit incorporation of performance estimation procedures for these devices into the operations analysis model; however, the small amount of data available indicates that the power and weight penalties imposed by these devices may be small, even at relatively high application rates.

These mechanical spreaders could be used in combination with either single or multiple point dispersal configurations incorporating either free release methods, conventional spreaders, or combinations of these types.

Additional studies are recommended in which analytical models would be developed for material transport mechanisms and mechanical spreaders, accounting for swath width and cross section produced, power required, and system weight, all as a function of material mass flow rate. These models would be added to the operations analysis program, and aircraft configurations incorporating various combinations of these concepts would be analyzed to establish the system configuration providing the highest productivity and lowest dry material dispersal cost.

4.8 MATERIAL LOADING CONCEPTS

The systems currently in use for loading both liquid and dry materials into the hoppers of agricultural aircraft have evolved over many years to satisfy specific requirements unique to the operation. Through this evolutionary process the equipment now available represents pragmatic design optimization, considering loading rates, equipment cost, reliability, maintainability, and support personnel requirements. Significant deviations from the design philosophy represented by this equipment would be difficult to justify unless a clear cost-effectiveness advantage could be documented and supported. Loading concepts different from those currently in use which can be defended as providing a clear cost-effectiveness advantage have not been developed to-date.

It is clear, however, that the time spent in loading the aircraft is non-productive time which subtracts from the productive potential of each operational day. To establish the influence of loading time on mission performance and cost, analyses were conducted in which the material loading rate was varied over a range from 25 lbs/sec (11.3 kg/sec) to 200 lbs/sec (90.7 kg/sec) for both liquid and dry dispersal missions. Current liquid loading systems typically operate up to 33 lbs/sec (15 kg/sec), and dry material loading systems up to 100 lbs/sec (45.4 kg/sec).

The results of these analyses are provided in Figure 78 for the small aircraft and Figure 79 for the large aircraft. The data presented in these figures show that mission productivity (acres/elapsed hour) increases rapidly as loading rate is increased from 25 pounds/sec (11.3 kg/sec) to 100 pound/sec (45.4 kg/sec) for both liquid and dry material and for both small and large aircraft. The rate of improvement decreases with increasing loading rate above 100 pounds/sec, but continues to show improvement up to 200 lbs/sec (90.7 kg/sec).

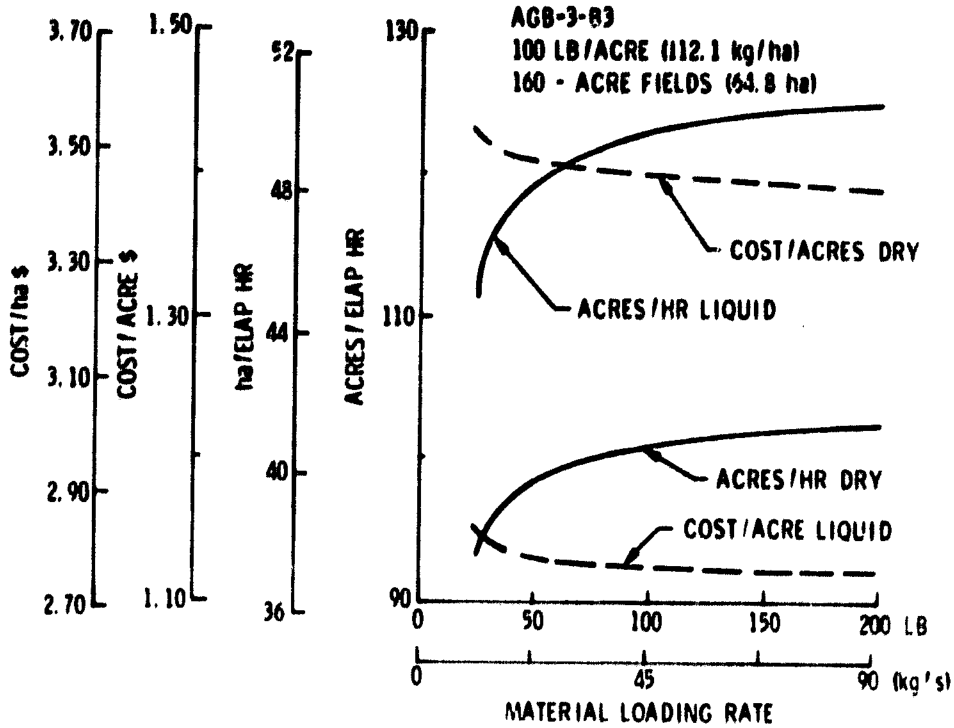

Figure 78. Effects of Material Loading Rate (AGB-3)

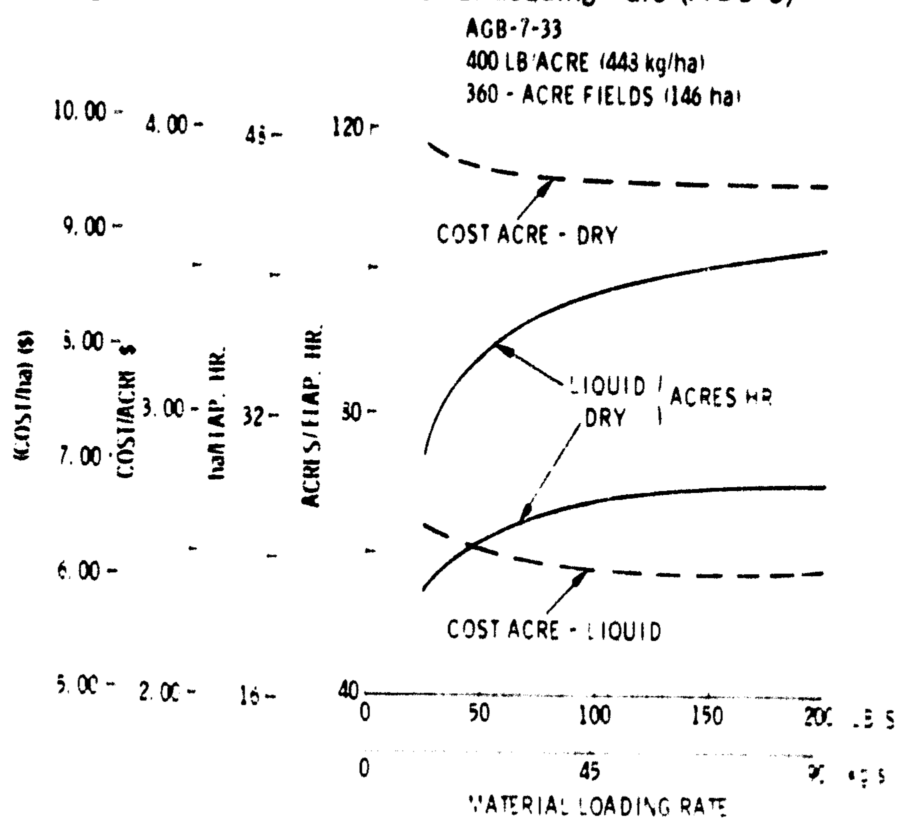

Figure 79. Effects of Material Loading Rate (AGB-7)

Increased loading rate does not directly affect aircraft operating cost. Mission costs are affected only by the reduction in total elapsed time; therefore, mission cost shows less improvement with increasing loading rate than productivity. Mission costs become essentially constant in the range of loading rates from 100 lbs/sec (45.4 kg/sec) to 200 lbs/sec (90.7 kg/sec). The capability to perform a given mission in fewer elapsed hours, however, would free the airport to perform additional work in a given time period, if such work is available. This has the potential for increasing aircraft utilization, which in turn would reduce fixed aircraft operating costs per flight hour. These effects could be significant in reducing mission costs but are not reflected in the present comparisons.

4.9 ALTERNATE CONFIGURATIONS

Through the process of developing and analyzing the baseline aircraft and investigating the sensitivity of the system configurations to many system parameters, including those of the dispersal and loading systems, several questions were raised regarding the possibility of improving mission performance by aircraft designs that incorporate features different from those of the baseline aircraft. Several alternate configurations have been developed and analyzed with the operations analysis model to evaluate these features.

4.9.1 Twin Reciprocating Engine Aircraft

A major contributor to the cost of the aerial application operations considered in this study is the cost of the turbine engines used for all applications requiring more than 400 horsepower (298 kw). Turboprop engines in the power range considered cost from $100 per horsepower ($134/kw) for the smallest to $120 per horsepower ($161/kw) for the largest. Non-turbocharged reciprocating engines in the 300 to 400 horsepower size cost approximately $35 to $40 per horsepower ($47 - $54/kw). Conversely, the turbine engines provide of the order of 2.5 horsepower per pound of weight (4.1 kw/kg), whereas the reciprocating engines provide approximately 0.7 horsepower per pound (1.2 kw/kg).

An investigation was undertaken to determine the mission performance relationship of the small baseline airplane to that of a twin reciprocating engine powered aircraft of essentially the same size and horsepower which provides less payload at lower operating cost. The restricted gross weight, design gross weight, and wing loading were held the same as that of the baseline, and the wing, empennage and fuselage were essentially unchanged.

The general arrangement of this configuration, designated AGB-3-2R1, is illustrated in Figure 80. The single turbine engine has been removed from the fuselage and replaced by two 350 horsepower (261 kw) non-turbocharged reciprocating engines in wing mounted nacelles. A ram air turbine is mounted in the nose of the fuselage to provide dispersal system power. The main landing gear struts are mounted on the engine nacelles.

The weight breakdown of this configuration is listed in Table XIX. The major change from that of the baseline aircraft is the increase in propulsion system weight. The overall effect is to reduce the payload from the baseline value of 3200 pounds (1452 kg) to 2800 pounds (1270 kg).

The operating cost of the aircraft was calculated using engine OEM costs of $13,500 each. The resulting aircraft operating cost per hour is $92.00, compared to the baseline aircraft cost of $98.00 per hour.

Aircraft drag and installed thrust were established, and the aircraft mission performance determined by the operations analysis model for liquid and dry dispersal missions. The results of this analysis are presented in Figures 81 and 82.

Productivity is shown in Figure 81 relative to that of the small baseline aircraft for application rates up to 400 lbs/acre (448.3 kg/ha). The dispersal missions were flown assuming [illegible]0% takeoff power during ferry and swath operations. This power level is considered the maximum allowable for reciprocating engines to achieve reasonable reliability and engine life. The combination of lower power level, slightly higher drag and less payload produce productivity considerably below that of the baseline aircraft, from

RESTRICTED GROSS WEIGHT -	7,650 LBS	(3,470 kg)
DESIGN GROSS WEIGHT -	5,925 LBS	(2,688 kg)
PAYLOAD WEIGHT -	2,800 LBS	(1,270 kg)
WING AREA -	380 SQ FT	(35 sq m)
INSTALLED HORSEPOWER -	2 X 350	
(KILOWATT) -	2 x 261	

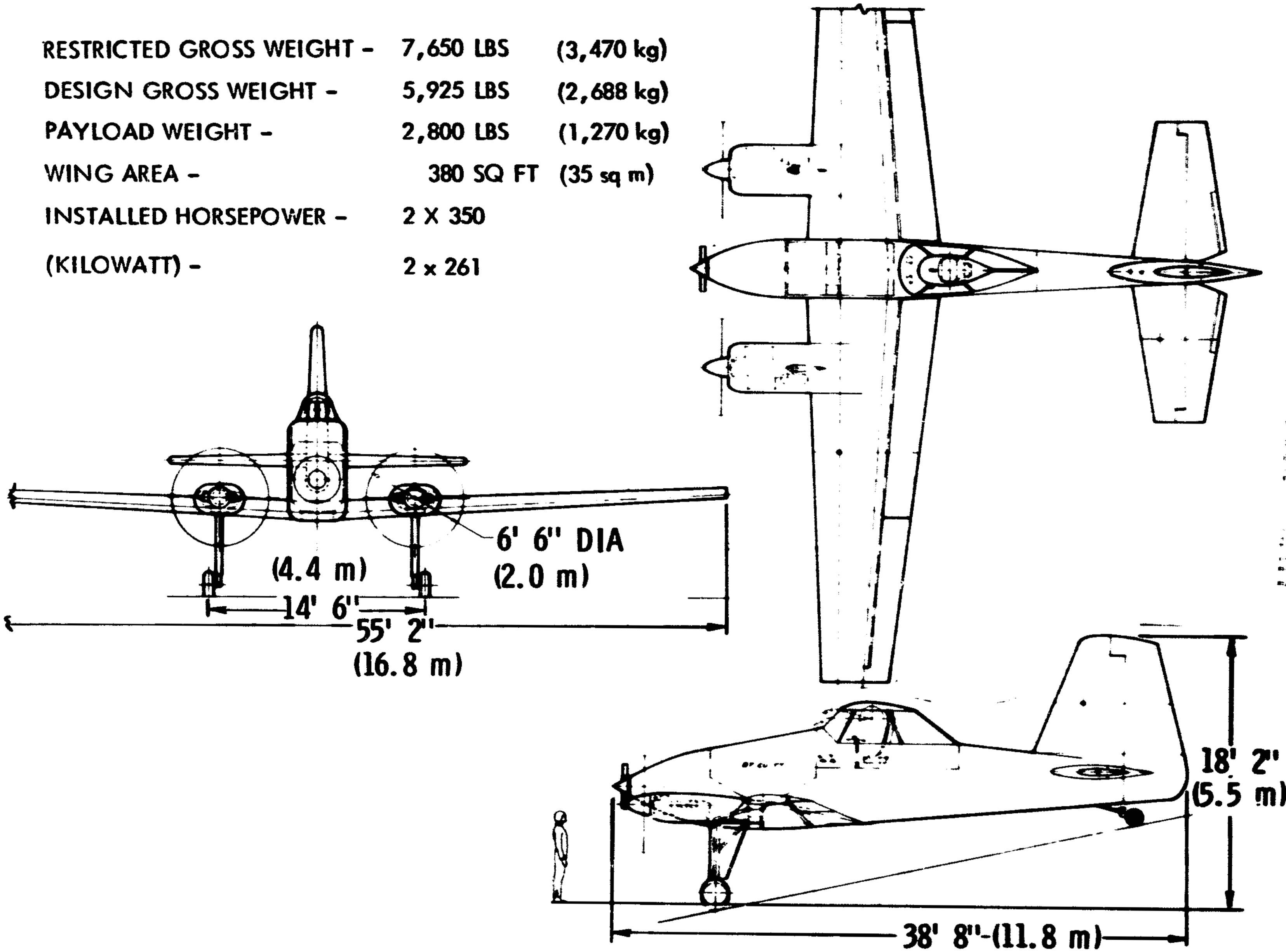

Figure 80. Configuration AGB-3-2R1

TABLE XIX - AGB-3-2R1 WEIGHT BREAKDOWN

	WING	700 LB.	(317 kg)
	EMPENNAGE	158	(72 kg)
	FUSELAGE	812	(386 kg)
	LANDING GEAR	310	(141 kg)
	PROPULSION	1655	(751 kg)
	A/C SYSTEMS	180	(82 kg)
	AG SYSTEMS	265	(120 kg)
EMPTY WEIGHT		4080	(1851 kg)
	PILOT	170	(77 kg)
OWE		4250	(1928 kg)
	FUEL	600	(272 kg)
ZERO PAYLOAD WEIGHT		4850	(2200 kg)
	PAYLOAD	2800	(1270 kg)
RESTRICTED GROSS WEIGHT		7650	(3470 kg)
FAR PART 23 GROSS WEIGHT		5925	(2688 kg)

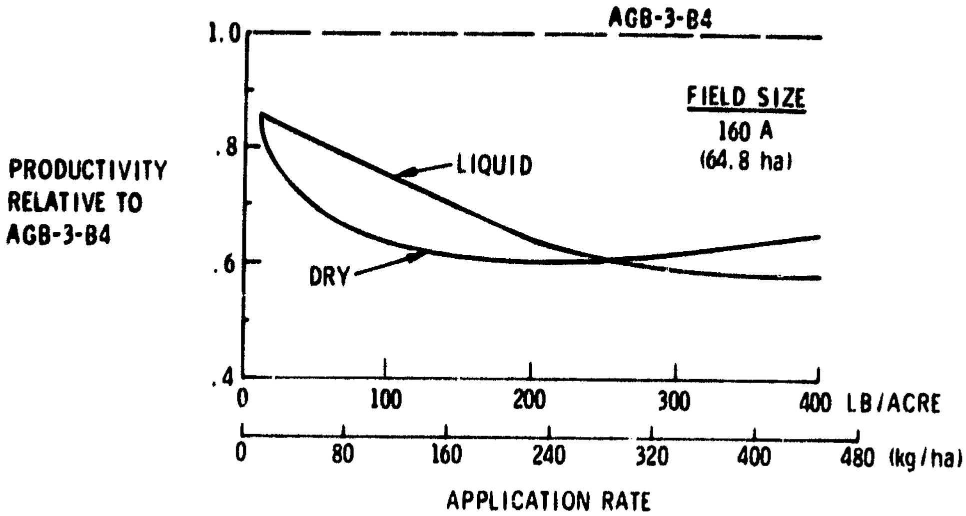

Figure 81. Configuration AGB-3-2R1 Productivity

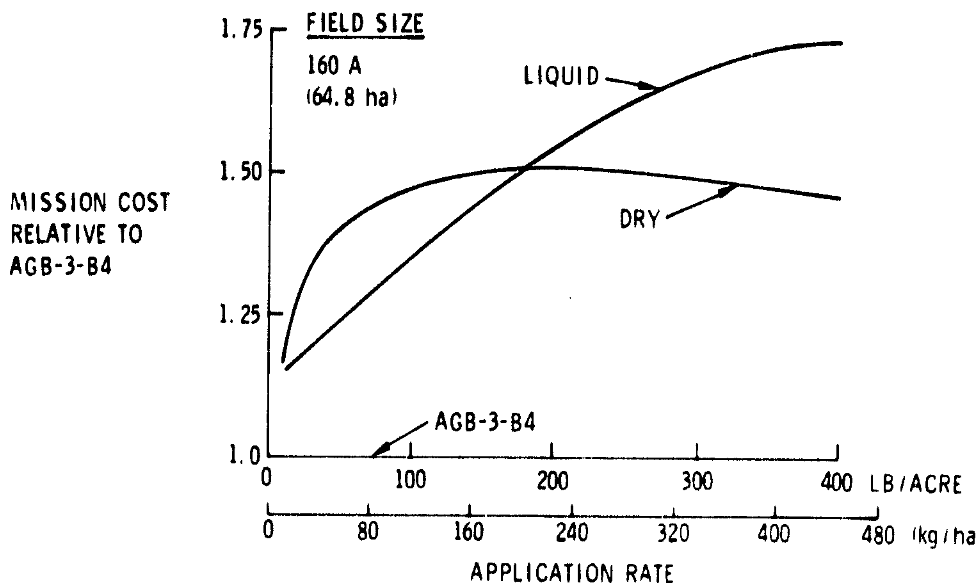

Figure 82. Configuration AGB-3-2R1 Mission Cost

80% of that of the baseline at low application rates to 60% at the higher rates.

Mission cost is shown in Figure 82 which indicates cost relative to that of the baseline. The lower operating cost of the twin does not adequately compensate for the reduced productivity; therefore, the cost/acre is higher at all application rates. Cost rises from approximately 15% greater than that of the baseline at low application rates to 50% greater for dry applications and 75% greater for liquid applications at 400 lb/acre (448.3 kg/ha).

From this analysis it appears that although reciprocating engines are significantly cheaper in cost, the loss of payload due to weight, the decrease in power due to engine life considerations, and the higher drag associated with recriprocating engine installations create a productivity penalty that cannot be offset by the cost advantage.

4.9.2 Unloaded Wing Biplane

Biplane configurations continue to represent a large percent of the ag aircraft population. This appears to reflect the good field performance characteristic of low wing loading, the crash safety provided the pilot by the upper wing, and good maneuverability reflected in high roll and pitch rates. The high drag and shorter wingspan of externally braced biplanes, however, have a detrimental effect on mission productvity.

The biplane configuration does offer a potential advantage that has not been investigated heretofore. That is, the utilization of the lower wing as the dispersal system boom, unloaded during the swath run to eliminate the tip vortex and associated particle entrapment problems, and loaded during the takeoff and turn to reduce the effective wing loading. Reduced wing loading during takeoff will improve field performance and during the turn will increase the achieveable load factor, decreasing the turn radius and turn time. Intrinsic merits of this concept include the reduction of dispersal system drag by enclosing the boom and plumbing in the lower wing, and an increase in the average lift coefficient of the upper wing during the swath which results in a higher average airplane lift/drag ratio.

To evaluate this concept, an unloaded lower wing biplane configuration of the same size as the large baseline aircraft was developed. This configuration, designated AGB-7-TB1, is illustrated in Figure 83.

Evaluation of the baseline aircraft revealed that wing span has the major influence on swath width capability of the airplane, and that swath width is a major factor affecting mission productivity. It was therefore desirable to not reduce the wingspan of the biplane below that of the baseline. To achieve this with two wings each of which has less individual area than that of the baseline requires a much higher aspect ratio and an associated higher wing weight, unless extensive external bracing is used. It was desirable to avoid the increased drag of external wing bracing.

The wing weight penalty was minimized by reducing the length of the cantilevered portion of the wings. This was achieved by separating the payload into two equal hoppers separated by the same spacing as that of the nacelles of the baseline aircraft. This approach permitted the incorporation of two additional features indicated in previous studies to have potential merit: (1) release of material from separated dispersal points and, (2) double the material loading rate using existing loaders to load the two hoppers simultaneously. The hopper configurations were adjusted to minimize total frontal area and provide upper and lower wing interconnecting structure at a spacing of no less than one chord length.

The upper and lower wing MAC 25% chord stations are aligned vertically in order to avoid trim changes as the lift is varied on the lower wing. The lower wing is a 21% thick symmetrical airfoil with relatively low taper in order to provide a large spanwise box which can be used to transport dry material outboard to the wingtip for release. The wings have full span flaps for use during takeoff. The lower wing flap is also deflected to approximately 8 degrees during turns to produce a wing loading essentially the same as that of the upper wing, 25 lbs/sq. ft. (122 kg/m^2) at

RESTRICTED GROSS WEIGHT -	15,300 LBS	(6,940 kg)
DESIGN GROSS WEIGHT -	12,500 LBS	(5,670 kg)
PAYLOAD WEIGHT -	6,925 LBS	(3,141 kg)
WING AREA -	618 SQ FT	(57 sq m)
INSTALLED HORSEPOWER	2 X 688	
(KILOWATT) -	(2 x 513)	

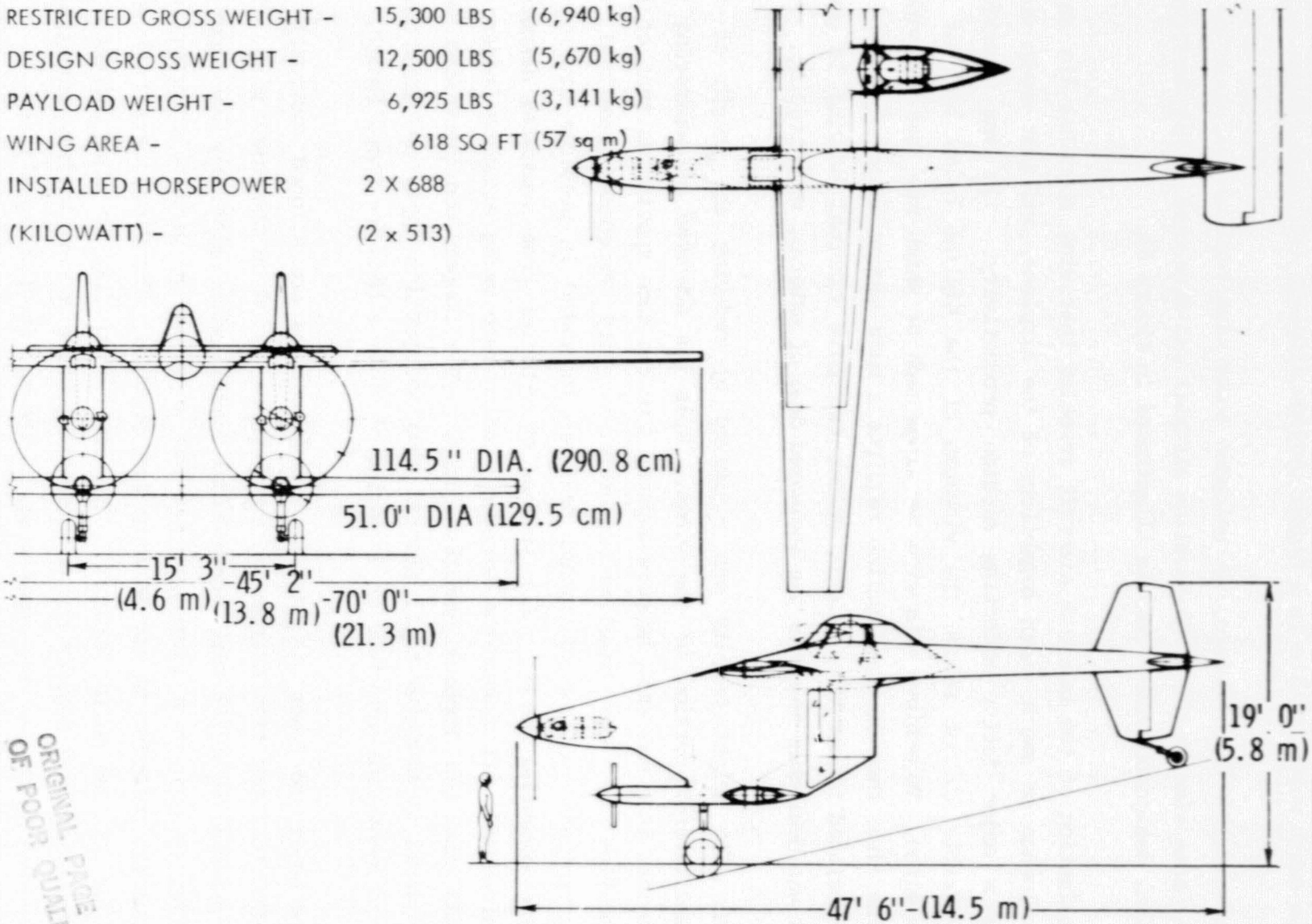

Figure 83. Configuration AGB-7-TB1

restricted gross weight. The flaps of the lower wing contains the liquid dispersal system plumbing with nozzles placed across the full span.

The lower wing incidence is selected to provide zero lift with no flap deflection at a gross weight midway between zero payload weight and maximum gross weight. The flap up-stop would be designed to permit the flap to be trimmed at a slightly upward position and to ratchet downward one increment after each flap deflection in order that the flap trim position would maintain near zero lower wing lift over a range of airplane gross weights, the increment being adjustable to reflect the material weight decrease during each swath. The flap actuator would be interconnected to the dispersal system valves or gates. When the gate is opened the flap will retract, and when the gate is closed the flap will deflect.

The span of the lower wing is approximately two-thirds that of the upper wing. This relationship was selected after examination of analytical plots of stream tube trajectories behind lifting wings. It appears that material injected in this spanwise region may be able to utilize the influence of trailing vortex circulation to maximum advantage in achieving the widest swath with a relatively low risk of being captured by the high energy vortex core. Confirmation of this is yet to be established, however, and should be the subject of future analytical and experimental investigation.

The empennage of the configuration is mounted on tail booms extending aft from the hopper/nacelle structure. The cockpit is located in a pod mounted behind the upper wing box on the aircraft centerline to provide maximum pilot visibility and crash protection. The main landing gear is mounted directly under the hoppers to provide a direct load path for the payload when the aircraft is on the ground.

Provisions are shown for two large ram air turbines (RAT) directly inline with the hopper exits. The RAT's illustrated are sized to provide 150 horsepower each at 135 kts, that required by the liquid dispersal system at application rates of approximately 400 lbs/acre (448.3 kg/ha).

The weight breakdown of the aircraft is listed in Table XX. The empty weight is approximately 700 pounds heavier than that of the baseline, resulting in a payload weight of 6925 pounds (3141 kg). Drag polars for the aircraft are based upon both wings lifting, upper wing only lifting, and both wings with flap settings equivalent to 20° for takeoff. Powerplant thrust was assumed to be the same as that of the baseline. Primarily because of the increase in empty weight, the operating cost of the biplane was determined to be $204.00 per hour, compared to 195.00 per hour for the baseline.

These data were used in the operations analysis model modified to permit swath runs and ferry on the upper wing only and takeoff and turns with both wings lifting. Three dispersal modes were investigated: liquid dispersal, dry material dispersal from conventional spreaders with 14 foot (4.3 m) separation, and dry dispersal by free release with 14 foot separation.

Productivity is plotted in Figure 84 relative to that of the large baseline aircraft up to 1000 lbs/acre (1121 kg/ha). The liquid dispersal productivity of the biplane is slightly less than the liquid dispersal productivity of the baseline at most application rates. This appears due to the fact that the reduction in liquid dispersal system drag provided by enclosing the system in the lower wing does not compensate for the lower payload weight.

The productivity of the aircraft using conventional dry spreaders relative to the baseline also using a conventional dry spreader is shown to be 25% to 30% lower across the entire application rate range. This appears to result from the combination of lower payload and the increase in conventional spreader drag associated with the increase in swath width created by separating the spreader into two sections, one under each hopper.

The productivity of the biplane using a free release method from each hopper separated by 14 feet relative to the baseline using free release from the single hopper is shown to be higher below 400 lbs/acre (448.3 kg/ha), increasing rapidly as the application rate decreases. Above 400 lbs/acre the relative productivity decreases to about 90% at 1000 lbs/acre

TABLE XX - AGB-7-TB1 WEIGHT BREAKDOWN

	WING	1760 LB.	(798 kg)
	EMPENNAGE	223	(101 kg)
	FUSELAGE	1765	(801 kg)
	LANDING GEAR	663	(301 kg)
	PROPULSION	1780	(807 kg)
	A/C SYSTEM	262	(119 kg)
	AG SYSTEMS	417	(189 kg)
EMPTY WEIGHT		6870	(3116 kg)
	PILOT	170	(77 kg)
OWE		7040	(3193 kg)
	FUEL	1335	(606 kg)
ZERO PAYLOAD WEIGHT		8375	(3799 kg)
	PAYLOAD	6925	(3141 kg)
RESTRICTED GROSS WEIGHT		15,300	(6940 kg)
FAR PART 23 GROSS WEIGHT		12,500	(5670 kg)

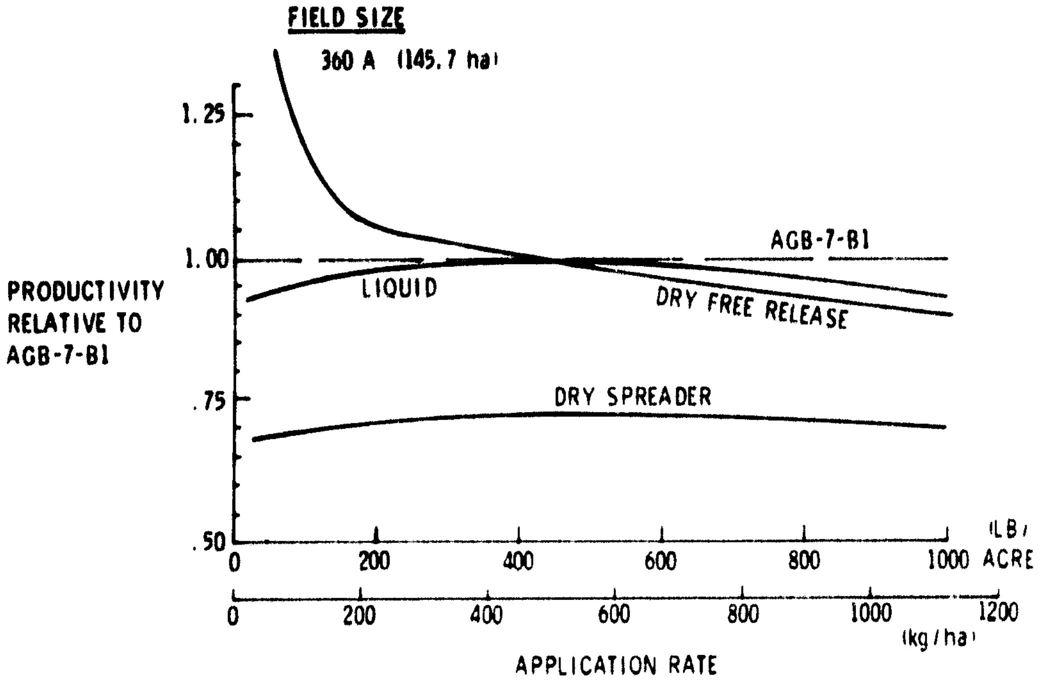

Figure 84. Configuration AGB-7-TB1 Productivity

(1121 kg/ha). The shape of this curve reflects the shift in relative importance of the effect of separated material dispersal points and lower payload as the application rate increases. As the application rate decreases the improvement in swath width resulting from dispersal separation rapidly overcomes the effect of the lower payload; whereas, at high rates the effect of lower payload on total ferry time overrides the influence of increased swath width.

Figure 85 presents the mission cost of the biplane for the three dispersal cases relative to the cost of the baseline. The cost/acre of liquid dispersal is from 5% to 15% more expensive across the application rate range. This reflects the higher operating cost of the biplane. The cost of the biplane using conventional dry spreaders is 50% to 60% greater than the baseline, indicating the penalty of both the lower productivity and higher operating cost. The cost of the biplane using the free release method is the same as that of the baseline at an application rate between 200 and 300 lbs/acre (224 and 336 kg/ha). At this point the slightly higher productivity is balanced by the slightly higher operational cost. At lower rates the cost/acre decreases rapidly; and at higher rates the cost increases to approximately 20% greater at 1000 lbs/acre (1121 kg/ha).

Both the productivity and cost/acre of the biplane can be improved approximately 10% if the dry material is transported through the lower wing and dispersed at multiple points out to a maximum separation distance equal to the lower wing span. Design studies of methods by which this material transport could most effectively be accomplished are recommended for future efforts.

The biplane configuration developed for this study is much more an assembly of ideas than a recommended configuration. It is intended to indicate that given adequate development an agricultural aircraft design can evolve which will combine the best features of those dispersal concepts that improve mission cost effectiveness. Additional development toward this end appears well justified.

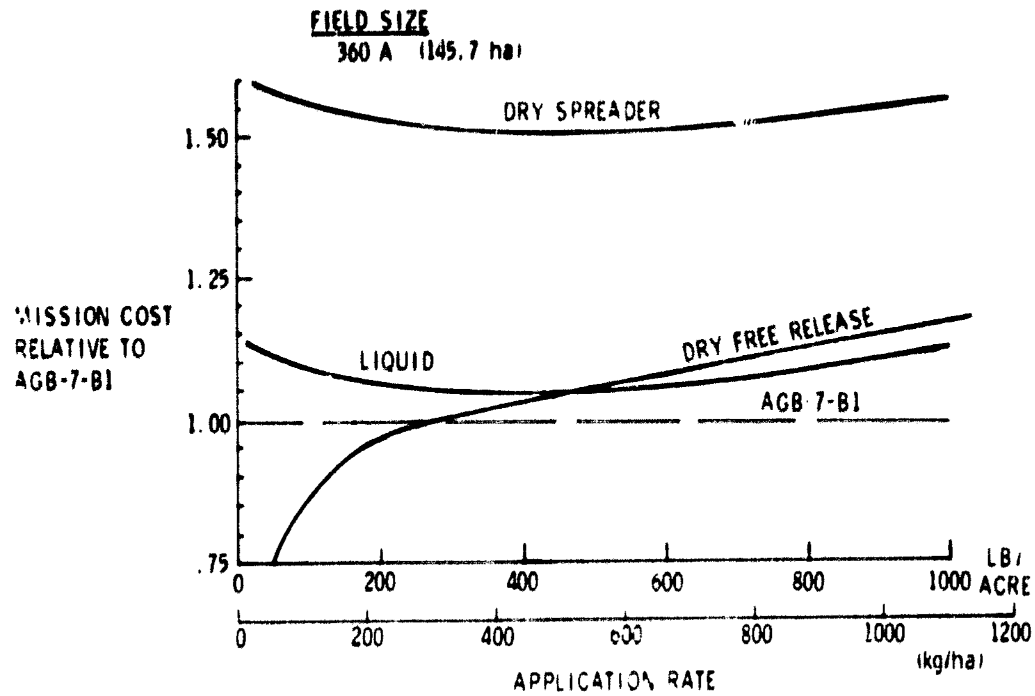

Figure 85. Configuration AGB-7-TB1 Mission Cost

4.9.3 Turbofan Engine Aircraft

In order to determine the merit of turbofan powerplants for agricultural missions, a turbofan powered version of the small baseline aircraft was developed and analyzed. This configuration, designated AGB-3-1F1, is illustrated in Figure 86.

The general arrangement of the aircraft retains the safety features of placing the powerplant and material hoppers separate from and ahead of the cockpit. This is achieved by mounting the engine nacelle on a pylon below and in front of the fuselage. The nacelle also supports the nose landing gear. Two hoppers each providing fifty cubic feet (1.4 cu. m.) are mounted in pod structures below the wing at a separation distance of approximately 16 feet (4.9 m). These structures also mount the main landing gear and support the liquid dispersal boom. The bottom of the hopper pods can mount conventional dry material spreaders, mechanical spreaders, such as rotary types, or permit free release directly from the hopper. The mission performance of the aircraft is determined using a dry dispersal system separation distance of 16 feet.

The weight breakdown of the aircraft is listed in Table XXI. The empty weight is approximately 200 pounds (91 kg) less than that of the baseline providing a corresponding increase in payload.

The most significant difference between this aircraft and the baselne is the initial and operating cost of the powerplant. The engine was sized to provide takeoff performance approximately the same as that of the baseline. The cost of this engine is 60% greater than the baseline engine, and this combined with the much higher turbofan fuel flow produces a cost per hour to operate the airplane of $154.00 per hour, compared to $98.00 per hour for the baseline.

The productivity of the turbofan aircraft relative to that of the baseline is shown in Figure 87. The liquid dispersal system productivity is approximately 5% to 10% higher across the range of application rates up to 400

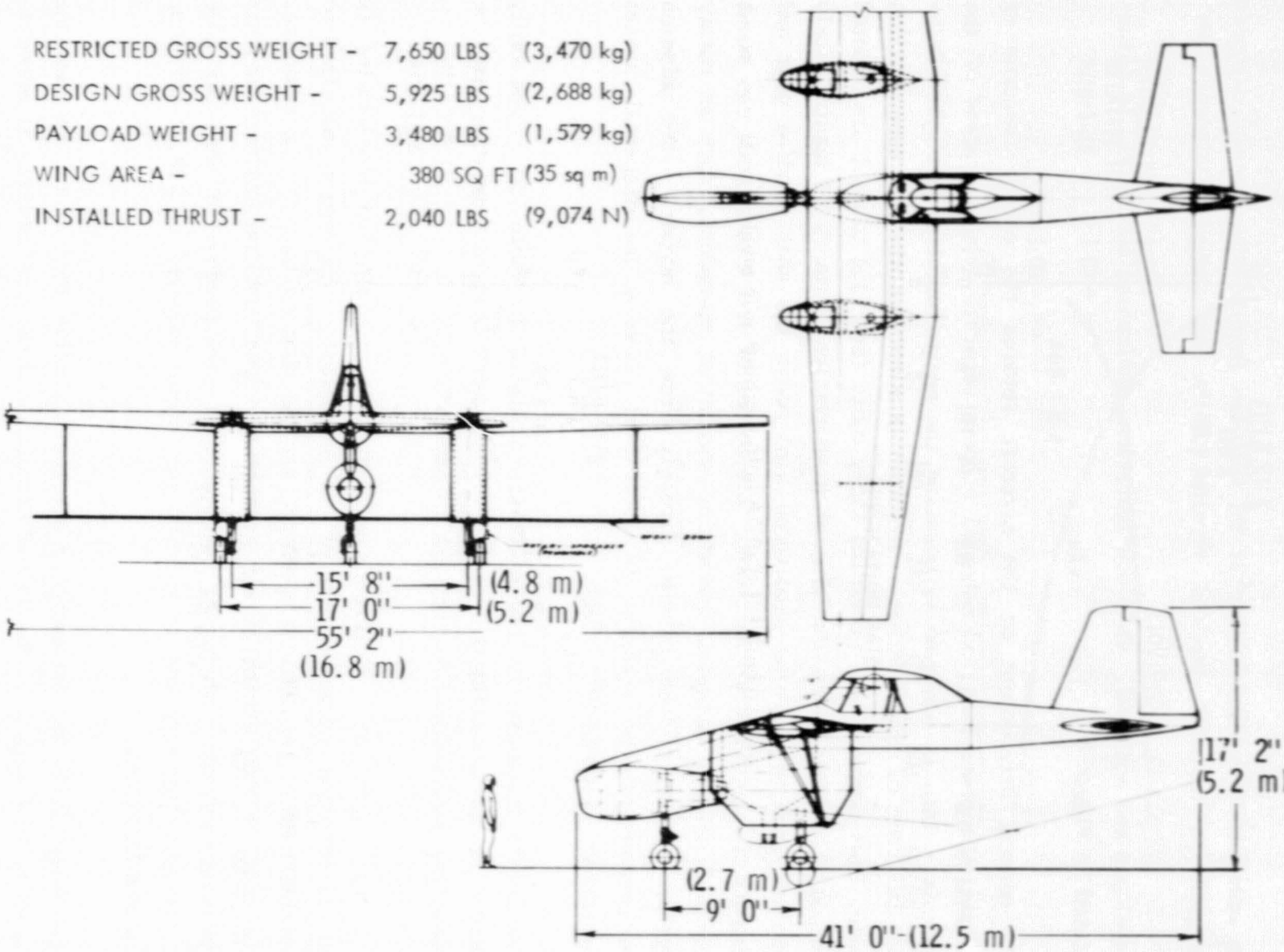

Figure 86. Configuration AGB-3-1F1

TABLE XXI - AGB-3-1F1 WEIGHT BREAKDOWN

	WING	760 LB.	(345 kg)
	EMPENNAGE	158	(72 kg)
	FUSELAGE	246	(111 kg)
	LANDING GEAR	330	(150 kg)
	PROPULSION	810	(367 kg)
	PYLON	90	(41 kg)
	NACELLE	126	(57 kg)
	A/C SYSTEMS	180	(82 kg)
	AG SYSTEMS	400	(181 kg)
	HOPPER STRUCTURE	300	(136 kg)
EMPTY WEIGHT		3400	(1542 kg)
	PILOT	170	(77 kg)
OWE		3570	(1619 kg)
	FUEL	600	(272 kg)
ZERO PAYLOAD WEIGHT		4170	(1891 kg)
	PAYLOAD	3480	(1579 kg)
RESTRICTED GROSS WEIGHT		7650	(3470 kg)
FAR PART 23 GROSS WEIGHT		5925	(2688 kg)

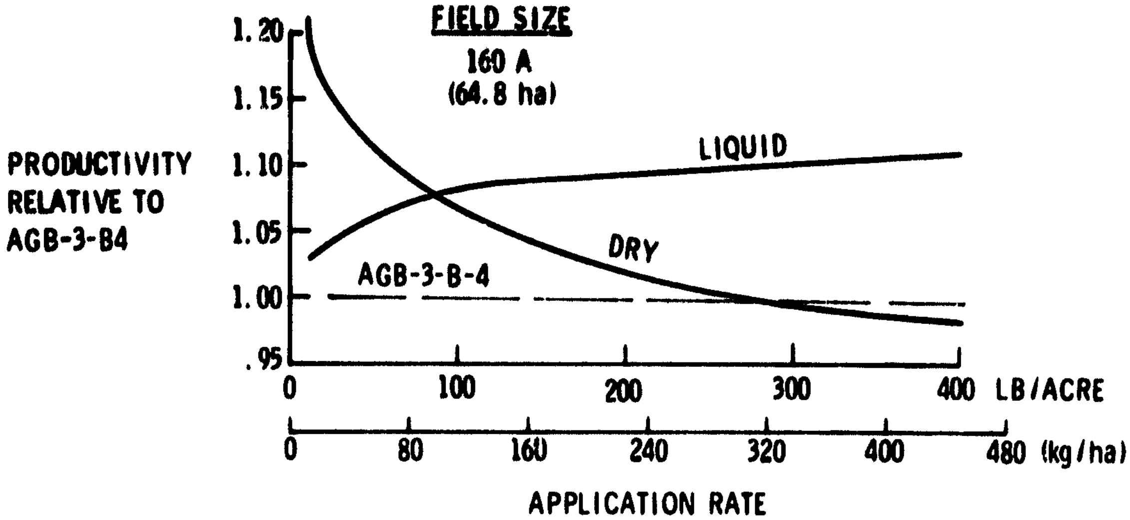

Figure 87. Configuration AGB-3-1F1 Productivity

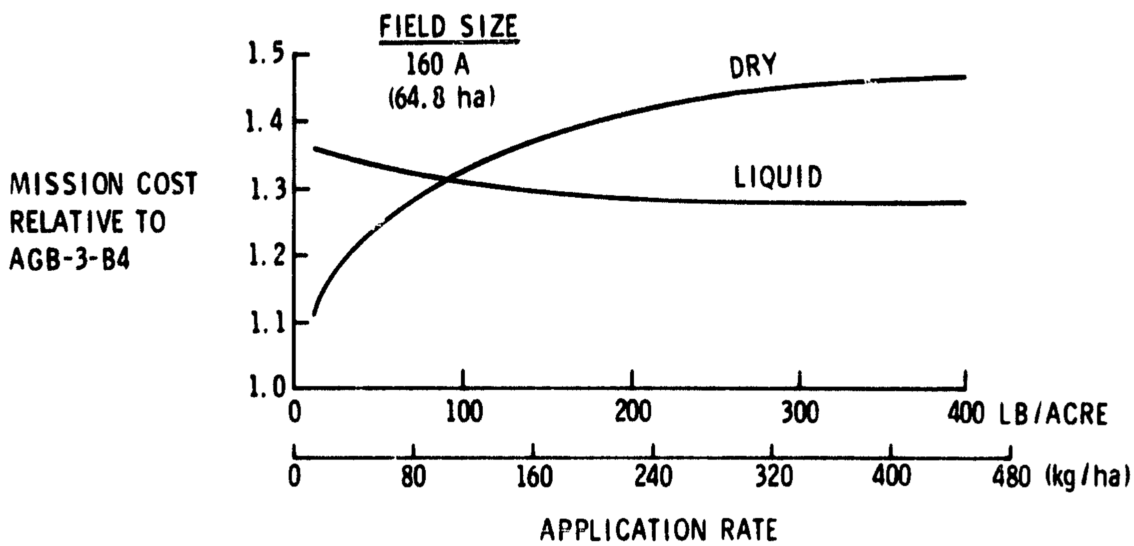

Figure 88. Configuration AGB-3-1F1 Mission Cost

lbs/acre (448.3 kg/ha). This appears due to the swath speed of the turbofan aircraft being slightly higher and the payload being slightly larger. The dry dispersal system productivity is significantly higher at low application rates but decreases to approximately equal productivity at application rates of 300 lbs/acre (336 kg/ha). The rise of productivity at low application rates results from the increase in swath width due to the 16 foot dispersal point separation.

The mission costs for the turbofan aircraft relative to the baseline costs are shown in Figure 88. The influence of the high operating cost of the turbofan is apparent. Except at low application rates of dry materials, all mission costs are in the range of 30% to 50% more expensive than the baseline.

The limited investigation of the turbofan powered agricultural aircraft reported here suggests that turbofan engines may be applicable in cases where productivity is the primary objective; but where mission economics must be considered, these powerplants do not appear to be competitive with turboprop powerplants.

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5.0 STRUCTURES AND MATERIALS

5.1 STRUCTURAL MATERIALS AND CONCEPTS

Several different types of airframe structural arrangements are used in current agricultural aircraft. A majority of aircraft use open truss, welded tubular steel framework fuselage structures. Some of these aircraft utilize conventional doped fabric covering, others use removable rigid skin panels of either aluminum or fiberglass. Open truss structures provide good access for cleaning out residual agricultural chemicals which settle in the structure and create serious corrosion problems in the primary, load-carrying structural members. Removable skin panels enhance the accessability for cleaning. Tubular steel truss structures are also attractive from the consideration of field repair of modest structural damage, where new tube sections can be welded in place of damaged tube sections with little preparation and structural alignment problems.

The advantages of the tubular truss structures are achieved at the expense of both a payload weight penalty and a higher fabrication cost, relative to a semi-monocoque aluminum fuselage. Statistical weight studies performed under Lockheed's independent development program indicate that a steel tube fuselage will be approximately 15% heavier than the equivalent monocoque aluminum structure. The disadvantage of the aluminum monocoque shell lies principally in the difficulty encountered in cleaning the residual chemicals from inaccessible locations, primarily in joints between structural members. Experience has shown corrosion to be a significantly more serious problem in monocoque structures.

Agricultural aircraft wing structures typically employ one or more spars as primary load-carrying members, with metal or fabric skin employed principally as an aerodynamic surface. While the corrosion environment is somewhat less severe than that encountered in fuselage structures, inspection and access for cleaning is usually more difficult. Also, because failure of the wing structure is more catastrophic than other structural components, the levels of corrosion that can be tolerated are lower. For these reasons, selection of wing structural materials and arrangement is critical to airplane design.

The corrosion environment and the cleaning and inspection problem are both severe for the empennage of agricultural aircraft. Consequently the selection of materials and structural configuration for the empennage presents a particularly difficult problem.

Advanced composite materials currently under development appear to offer both increased resistance to corrosion and increased structural efficiency in comparison to metallic structure. The composites considered to have the greatest promise for application in agricultural aircraft are graphite, Kevlar, and fiberglass reinforcements encapsulated either in epoxy (thermosetting) or polysulfone (thermoplastic) resin matrices. The thermosetting resin matrix composites are suitable for fabricating into parts by laminating and compression molding techniques requiring a pressure and temperature cure to retain their shape. The thermoplastic composites, on the other hand, lend themselves to thermoforming fabrication techniques, retaining their molded shape upon cool-down below their glass transition temperature. Thermoforming fabrication of composites is anticipated to have definite cost advantages by the 1985 time frame, with the thermoplastic composite material cost only slightly higher than the thermosetting composite material cost.

Table XXII shows a comparison of the three composite materials with respect to material cost, density, strength and stiffness. Aluminum is included in the table for material cost and density comparisons. Kevlar and graphite composites are relatively new and their cost is quite high relative to aluminum and fiberglass. Cost of these advanced composites has been steadily decreasing, however, and further cost reductions are projected as usage increases in the future. By 1985, material cost is expected to be approximately $10 per pound for Kevlar and $20 per pound for graphite, with both materials having long-range potential below $5 per pound. Advanced composites are already cost competitive with aluminum in some structural applications because of advantages in fabrication techniques.

TABLE XXII - STRUCTURAL MATERIALS COMPARISON

MATERIAL	MATERIAL COST* $/LB	($/kg)	MATERIAL DENSITY LB/IN^3	(kg/cm^3)	STRENGTH	STIFFNESS
COMPOSITE						
FIBERGLASS	3	(6.6)	0.070	(.0019)	About	Lowest
KEVLAR	20	(44.1)	0.050	(.0014)	Equal	Medium
GRAPHITE	40	(88.2)	0.057	(.0016)		Highest
METAL						
ALUMINUM	2	(4.4)	0.100	(.00288)		

*APPROXIMATE AVERAGES.

Since fiberglass composites are approximately 70 percent the weight of aluminum, weight savings can be achieved with this material for minimum gage design applications. Greater weight savings are possible with Kevlar and graphite in the same applications, since their densities are approximately two-thirds that of the fiberglass composites while their strengths are essentially the same. Stiffness properties, however, favor graphite and Kevlar over fiberglass in many applications. Advantages may often be attained through hybrid combinations of these composites utilizing each of the materials to its greatest advantage. For example, skin and stiffener webs may be constructed with the more economical fiberglass composite with Kevlar or graphite being selectively used for stiffness in cap areas.

Numerous government and industry programs on application of composites have been conducted over the past several years. Reference 26 lists 120 programs involving fabrication of composite hardware in various aerospace applications including rotor blades, radomes, fairings, fan blades, wing, fuselage, empennage, landing gear, aileron, speed brake, fasteners, cargo doors, weapons bay doors, access doors, and other items. Figures 89 through 92 show some typical composite applications for specific aircraft.

Figure 89 is a full-scale semi-span Remotely Piloted Vehicle (RPV) wing fabricated under a current Air Force program. The wing is 70 inches long and 16 inches in chord and consists of an all-graphite/epoxy skin with integrally molded spars fabricated in a single stage molding operation. A test panel designed for the JetStar fuselage is shown in Figure 90. This panel has a fiberglass and graphite/epoxy skin stabilized with stringers and rings having fiberglass webs and graphite caps, thus making it a hybrid structure. Figure 91 shows a fiberglass-graphite/epoxy hybrid wing leading edge for the C-141 that is currently being fabricated under contract with the Air Force Materials Laboratory. The leading edge skin consists of fiberglass and graphite/epoxy composite. The stiffener and rib webs are fiberglass/epoxy composite, and the caps are unidirectional graphite/epoxy composite. Figure 92 shows an all-graphite/epoxy test spar designed for

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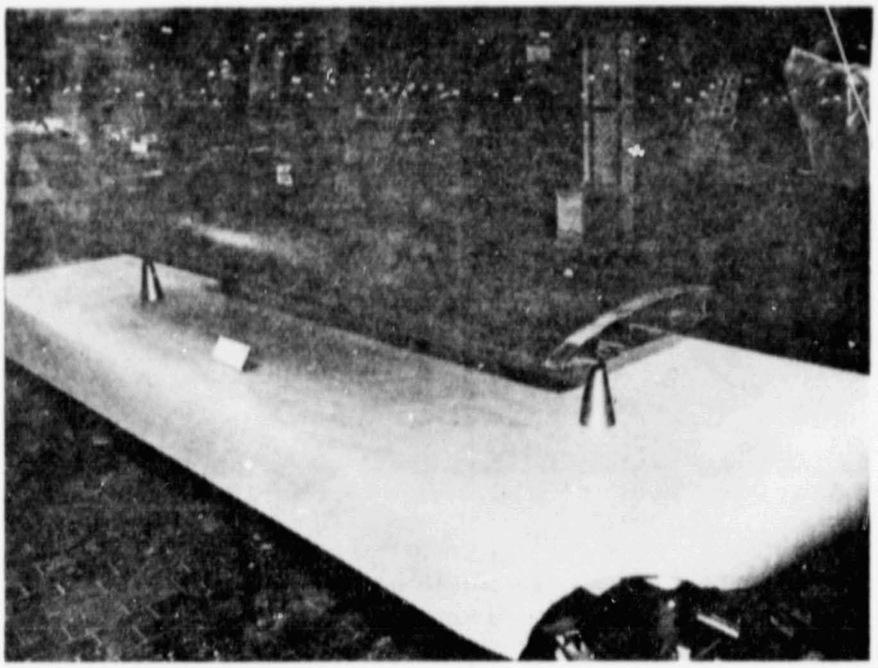


Figure 89. All Graphite RPV Wing

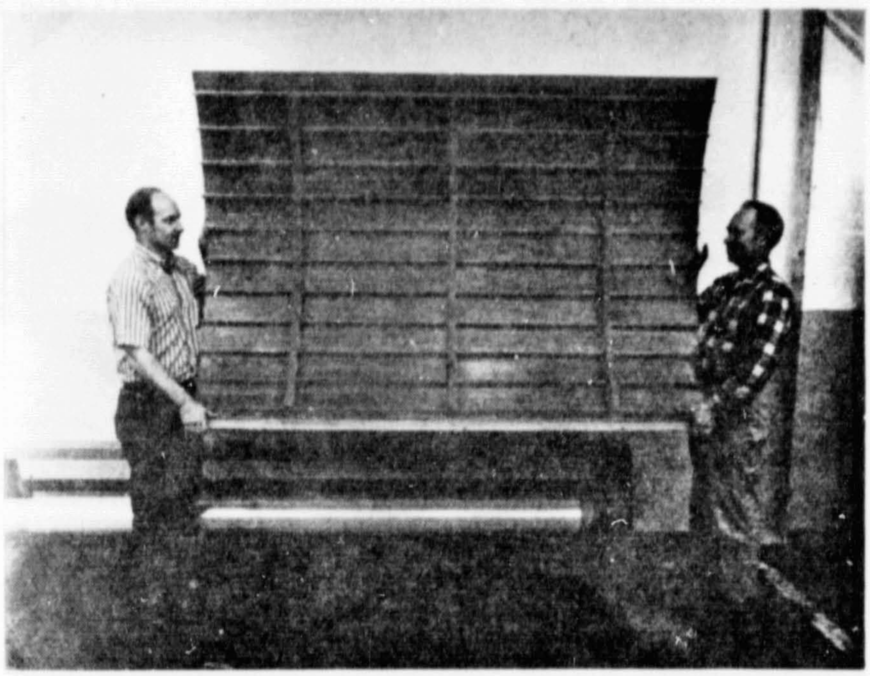
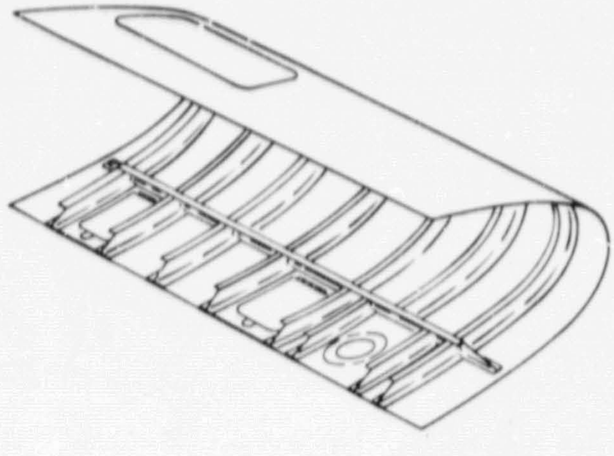


Figure 90. JetStar Graphite Fiberglass/Epoxy Fuselage Panel



- INTEGRALLY MOLDED
- SKIN-RIB-STRINGER CONSTRUCTION
- PRELIMINARY DESIGN CONCEPT
  - SKIN - "E" GLASS EPOXY AND GRAPHITE EPOXY
  - STIFFENER WEBS - "E" GLASS EPOXY
  - STIFFENER CAPS - GRAPHITE EPOXY

Figure 91. C-141A Fiberglass-Graphite/Epoxy Wing Leading Edge

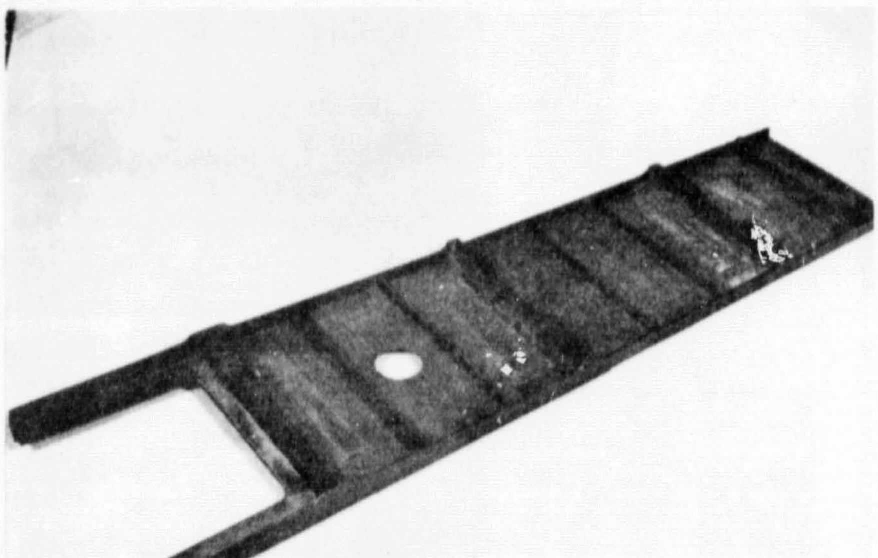


Figure 92. L-1011 Graphite/Epoxy Vertical Fin Spar Section

the L-1011 vertical fin. This complete structure including web, caps and stiffeners is fabricated in a one-step molding operation.

Examples of current design concepts for composite aircraft structures are shown in Figures 93 through 96. Figure 93 shows three types of skin panels applicable to fuselage, wing, and empennage surfaces: a honeycomb sandwich using fiberglass or Nomex core bonded to composite face sheets incorporating aluminum mesh on the outer surface to prevent catastrophic failure in the event of a lightning strike; an integrally molded blade stiffened panel; and skin panels stiffened by molded hat sections bonded to the panels. Methods of incorporating these panels in wing or empennage construction are indicated in Figure 94. Methods of incorporating sandwich and integrally stiffened panels in low-cost composite fuselage structures are illustrated in Figures 95 and 96.

It is technically fesible within the current state of technology to employ composite materials in almost all structural areas of the aircraft. However, widespread production usage of advanced composite aircraft structures has not yet advanced to a state of general acceptance because of such factors as materials cost and lack of service experience. With additional experience from current and future application programs, these materials may well be competitive for agricultural aircraft designs in the 1985 time period.

5.2 COMPOSITE MATERIALS FOR WEIGHT REDUCTION

The sensitivity analysis of aircraft structural weight showed that reduced weight provides major benefits in mission economics. In general, composite materials technology offers the most promising approach for significant structural weight reduction in future aircraft. Weight savings with composites will vary, however, depending on the type of aircraft and specific structural requirements imposed by the mission.

An analysis has been performed to determine the approximate weight savings that would be possible in agricultural aircraft with a high degree of composite material applications. The small baseline study aircraft was used

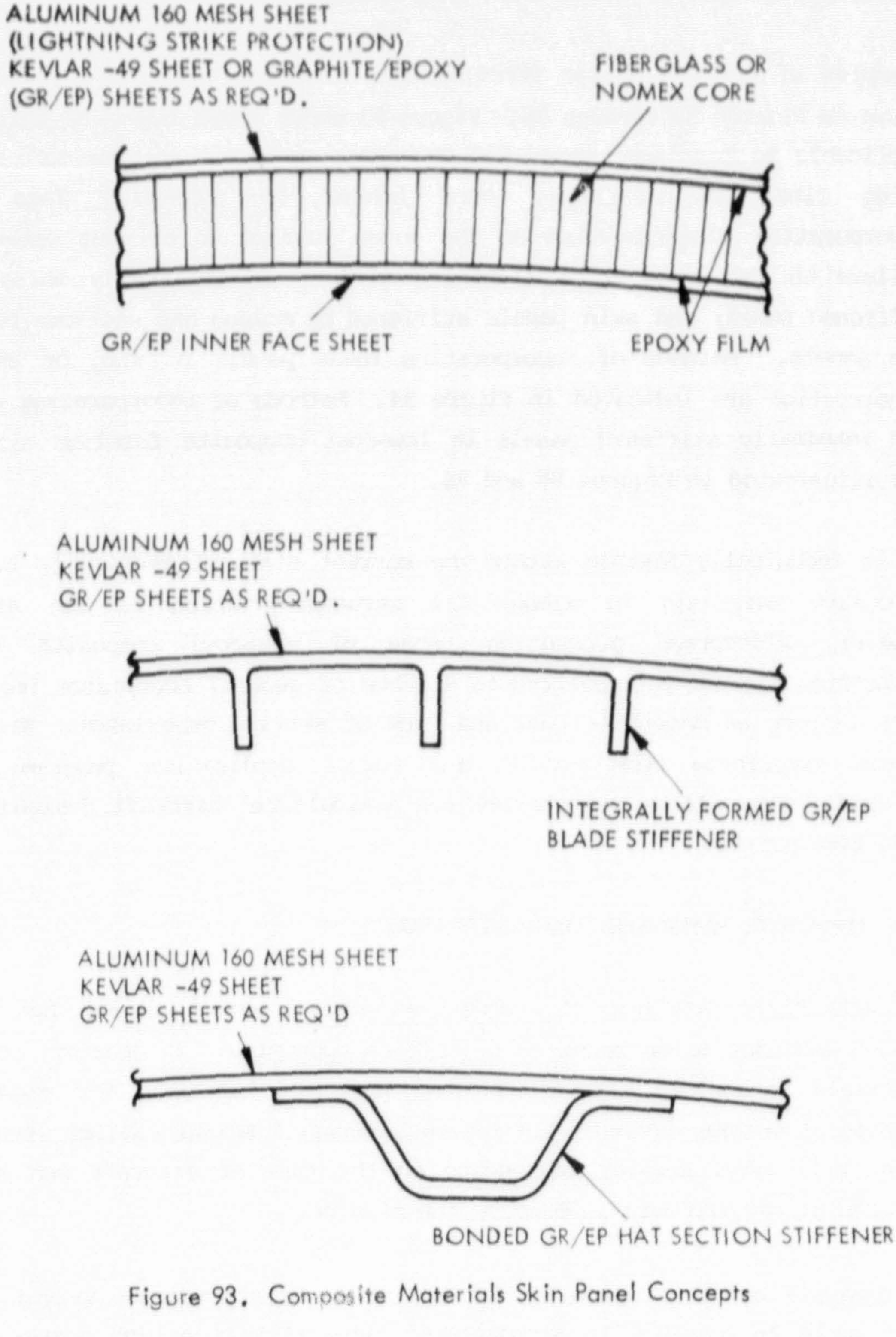
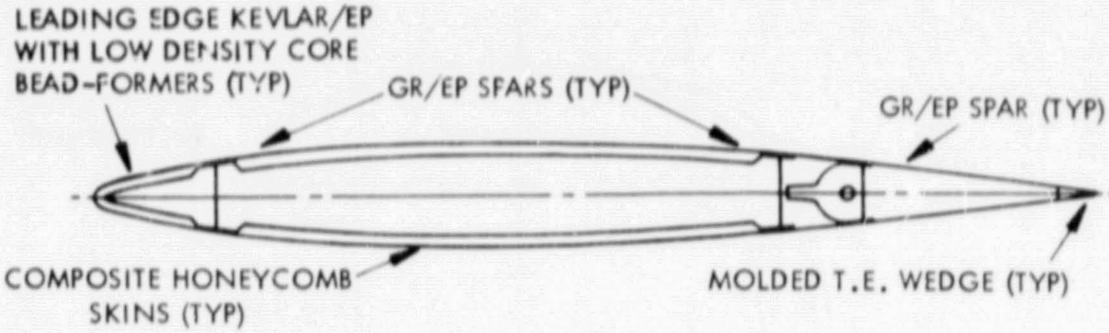
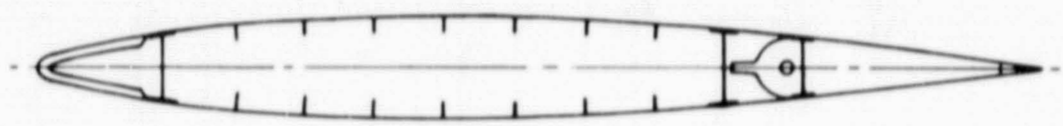


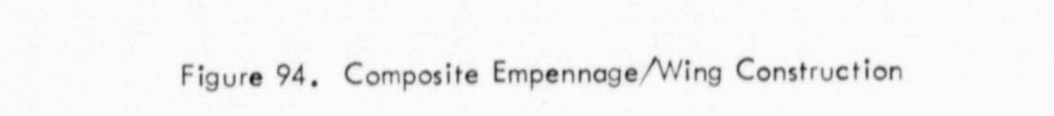
Figure 93. Composite Materials Skin Panel Concepts



SANDWICH SKIN PANEL CONSTRUCTION



INTEGRAL BLADE STIFFENED CONSTRUCTION



HAT SECTION STIFFENED CONSTRUCTION

Figure 94. Composite Empennage/Wing Construction

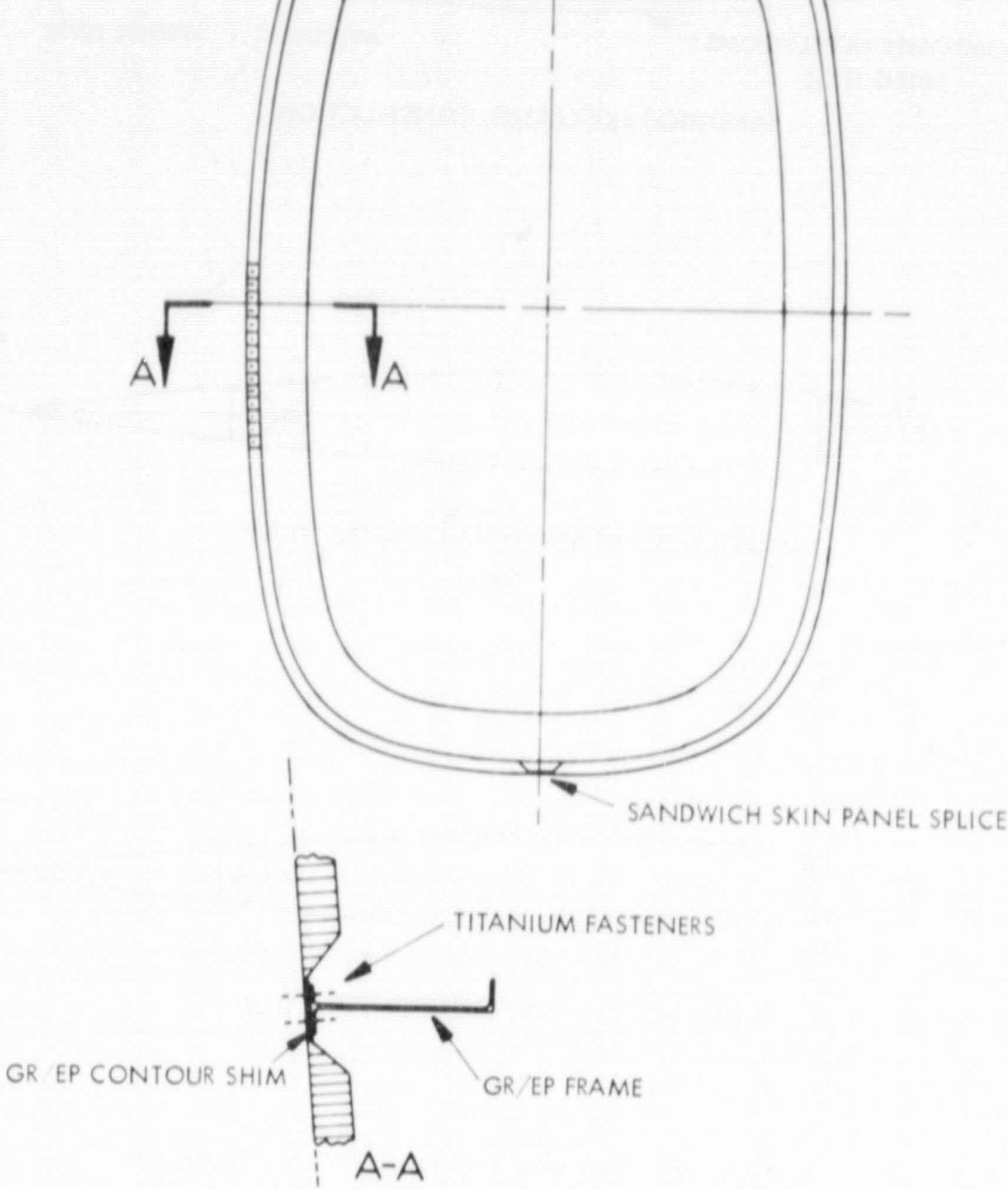


Figure 95. Composite Fuselage Sandwich Panel Construction

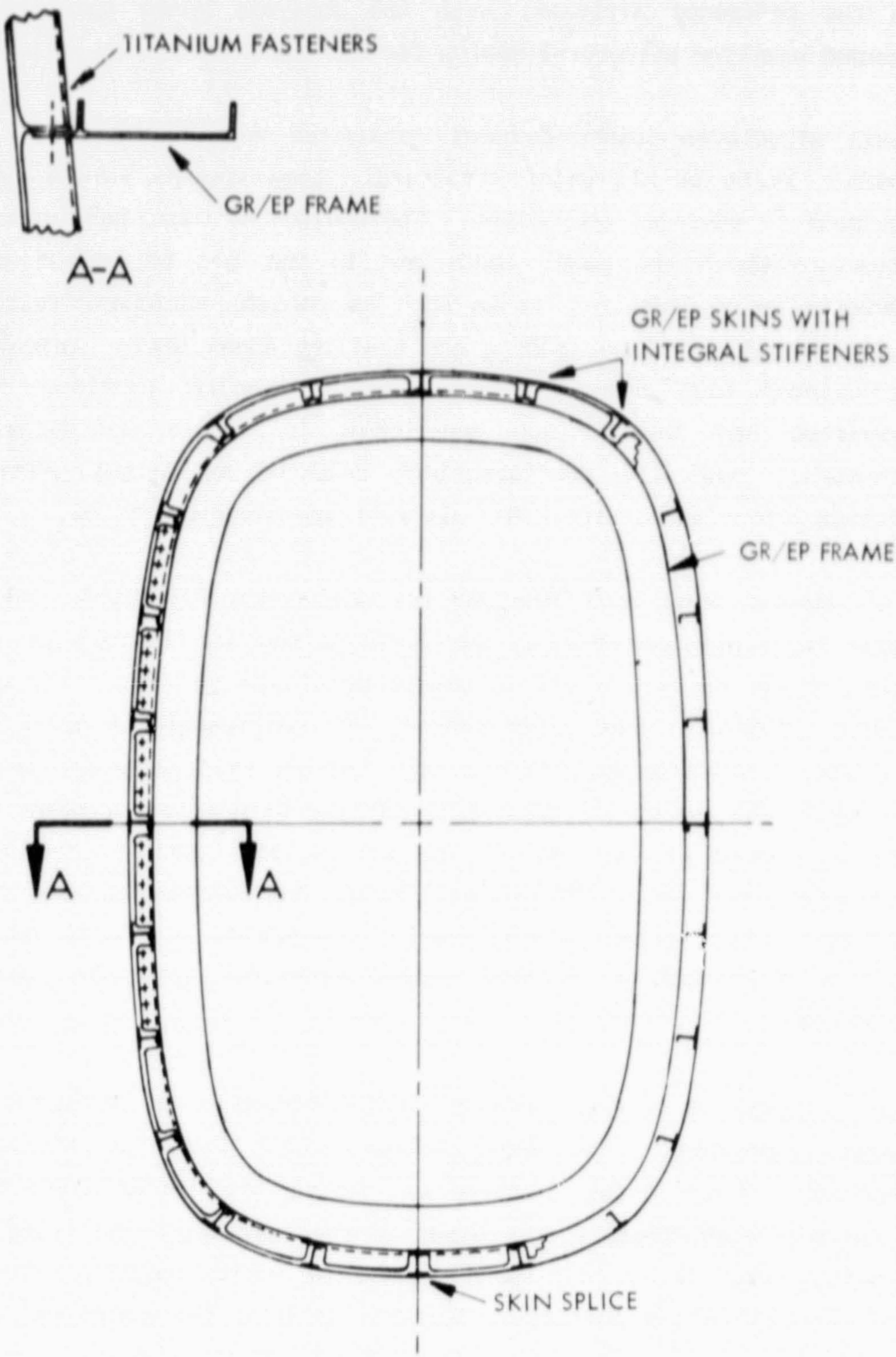


Figure 96. Composite Fuselage Integrally Stiffened Molded Construction

as the reference airframe, with the analysis based specifically on an assumed baseline structural design for the AGB-3-B4 configuration.

Basic structures using advanced composites were sized using preliminary loads. Parts of all major structural items show a weight savings when designed in advanced composites. The savings are more easily recognized in structure where the panel loads are in the low to medium range, e.g. 1000#/in to 10,000#/in. Areas such as control surfaces, fairing panels, and wing and empennage leading and trailing edges where minimum gages are encountered also offer potential weight savings provided buckling is permitted and the surface smoothness is within aerodynamic limits. Conceptual composite configurations selected as having greatest weight savings potential for the AGB-3 aircraft are described below.

The selected wing is a two-spar box with skin, stringers, and ribs. The spars are continuous through the fuselage and are located at 25% and 65% chord. The spars are all composite materials and carry the wing-bending loads. They will have approximately 20% unidirectional graphite/epoxy in the caps. The remainder of the caps and web will be Kevlar or fiberglass. The spar webs are of the tension field type with integral blade stiffeners. The skin is of minimum gage Kevlar and is stabilized by integral stringers and aluminum ribs. The skins, ribs, and stringers are mechanically fastened. From a limited engineering assessment, this wing concept appears to be the most weight-efficient structure available with current technology.

The fuselage is a skin-longeron configuration. It is made up of three major components. Two shell halves extend from the firewall to the empennage attach joint. These two halves are joined along the top and constitute approximately two-thirds of the fuselage. The third piece is a non-structural belly panel which would be easily removable for inspection and cleaning of the fuselage interior. Each of the structural halves have two fiberglass longerons which are reinforced with graphite. The skins are fiberglass with burlap as the inner layer to provide increased stiffness. Bulkhead segments are formed into the shell halves at each end to maintain shape and for loads redistribution. Intermediate formers are added as needed. In the cockpit area, the top and longerons divide and form the edging members around the opening. The cockpit floor and forward and aft bulkheads are added by means of mechanical fastening to the shell halves. An outward collapsing steel tube cage would surround the cockpit area.

The structure of the horizontal and vertical stabilizers is similar to that of the wing. Both utilize the spar concept with light skins.

The flat spring struts of the main landing gear are made of high modulus graphite composite, and the geometry is tailored to maintain uniform strain.

Weights for the structural components of the AGB-3 composite airplane configuration were estimated by analytical means using layout sketches and stress analysis. The weight breakdown of the baseline aluminum aircraft and the composite aircraft are presented in Table XXIII. The estimated weight reduction with composite materials is approximately 234 pounds (106 kg), which results in an empty weight for the composite aircraft that is 93% of the baseline metal aircraft. This allows a corresponding increase in payload for the composite aircraft for the same restricted category gross weight as the metal aircraft.

5.3 COMPOSITE AIRCRAFT COST AND MISSION ANALYSIS

5.3.1 Cost Analysis

An engineering estimate was made of the cost of the structural elements of the composite materials aircraft relative to conventional metal structure. Manhour and material cost estimates were based on types and approximate quantities of the various materials assumed in the weight analysis; average prevailing costs per pound for the different materials; an assessment of fabrication and assembly methods likely to be employed; and typical manufacturing labor requirements. Approximate cost factors for the composite structure relative to a conventional aluminum configuration are given in Table XXIV.

TABLE XXIII - COMPOSITE AIRCRAFT WEIGHT BREAKDOWN

		AGB-3-B4		ALL-COMPOSITE AIRCRAFT	
	WING	855 LB.	(388 kg)	701 LB.	(318 kg)
	EMPENNAGE	158	(72 kg)	142	(65 kg)
	LANDING GEAR	344	(156 kg)	327	(148 kg)
	FUSELAGE	934	(424 kg)	887	(402 kg)
	PROPULSION	832	(377 kg)	832	(377 kg)
	A/C SYSTEMS	180	(82 kg)	180	(82 kg)
	AG SYSTEMS	265	(120 kg)	265	(120 kg)
EMPTY WT.		3568	(1619 kg)	3334	(1512 kg)
	PILOT	170	(77 kg)	170	(77 kg)
OWE		3738	(1696 kg)	3504	(1589 kg)
	FUEL	662	(300 kg)	662	(300 kg)
ZERO PAYLOAD WT.		4400	(1996 kg)	4166	(1889 kg)
	PAYLOAD	3200	(1451 kg)	3434	(1558 kg)
RESTRICTED GROSS WT.		7600	(3447 kg)	7600	(3447 kg)

TABLE XXIV - COST FACTORS FOR COMPOSITE

MATERIALS STRUCTURE AGB-3-B4 CONFIGURATION

	COST OF COMPOSITE STRUCTURE RELATIVE TO ALUMINUM	
	LABOR COST	MATERIALS COST
WING	1.34	2.31
FUSELAGE	1.20	2.61
EMPENNAGE	1.35	2.36
LANDING GEAR	1.10	1.38

These factors were applied to the AGB-3-B4 airframe costs to obtain estimated costs for the composite aircraft. Since the acquisition cost methodology does not provide cost estimates for individual structural elements, it was first necessary to determine the approximate proportion of AGB-3-B4 airframe costs attributable to the structural items. This was accomplished by use of proportional factors developed from typical light aircraft structural cost data published in a previous NASA study (reference 27).

The analysis indicated that cost of the composite structure would increase by approximately 49% over conventional metal structure for the AGB-3-B4 configuration. However, the composite structure accounts for less than a third of the total aircraft factory cost, since the turboprop engine is by far the dominant cost factor. Aircraft acquisition cost was found to increase only about 11% with the composite structure.

Operating costs for the composite aircraft were calculated by the standard cost equations used for other aircraft configurations. In this case aircraft maintenance was assumed to be the same as for the conventional aircraft, since it was not possible within the scope of the present study to determine relative maintenance costs between composite structure and metal structure. The only operating cost elements changed from the baseline aircraft were annualized investment and hull insurance, both of which were increased commensurate with the higher acquisition cost of the composite aircraft. Overall operating cost for the composite aircraft was found to increase by only 5% over the baseline metal aircraft.

It should be noted that the cost estimates for the composite aircraft are of a lower confidence level than those for the baseline configuration. While the results are acceptable as approximations, more detailed analyses are needed to establish confidence in the cost implications of advanced composite material applications for agricultural aircraft.

5.3.2 Mission Analysis

5.3.2.1 All-composite Aircraft - The composite aircraft was evaluated with the operations analysis model and compared with the baseline metal aircraft over a range of liquid and dry missions. The mission productivity comparison is given in Figure 97, which shows that the composite aircraft has greater productivity in both liquid and dry material cases. This reflects the higher payload of the composite aircraft, which is of increasing benefit as the application rate increases.

Figure 98 shows the mission cost comparison. These data indicate that the composite aircraft is competitive with the baseline metal aircraft in dry missions, with some economic advantage at the higher application rates. For liquid missions, the composite aircraft shows a distinct advantage for application rates above 80 pounds per acre (90 kg/ha). It is apparent that the increase in operating cost for the composite aircraft is more than offset by the gain in productivity except in low-volume liquid missions.

5.3.2.2 Aircraft with Composite Wings - Since the greatest portion of the weight savings with composite materials was in the wing, an analysis was made of cases in which a composite wing is used with conventional baseline metal construction in other structural areas. Other studies have shown that composite-material wing designs tend to optimize at higher aspect ratios than conventional metal wings because of the trade-off between wing weight and induced drag. In addition, agricultural aircraft productivity has been shown to benefit from increased wing span because of an improvement in swath width. Agricultural aircraft might therefore benefit from higher aspect ratio wings when composite materials are used.

The composite wing study was performed for the AGB-3-B4 configuration for composite wings with aspect ratios of 8, 10, and 12. In this case, only the cost of manufacturing the wing was changed from the baseline metal aircraft, using the same factors developed for the wing in the all-composite aircraft analysis. These results showed an increase of about 5% in acquisition cost and 2% in operating cost over the baseline metal aircraft. Weight and drag estimates were developed for each different

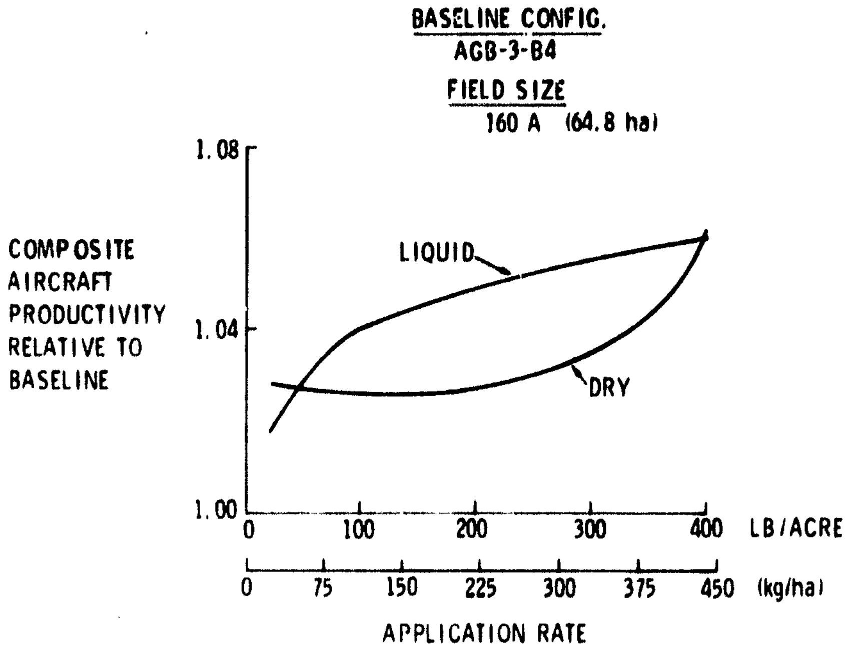


Figure 97. Composite Materials Aircraft Mission Productivity

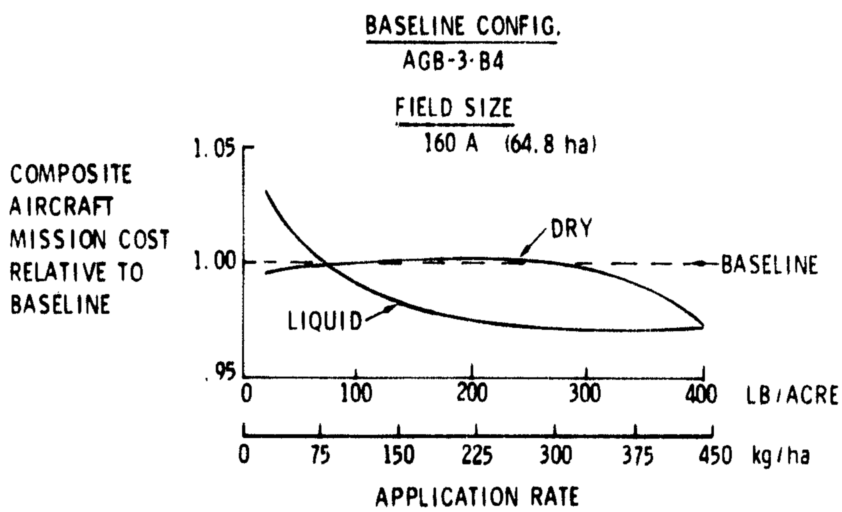


Figure 98. Composite Materials Aircraft Mission Cost

aspect ratio wing, reflecting increasing weight and decreasing drag as aspect ratio is increased.

Productivity in liquid missions of the various aspect ratio cases and the composite airframe case is shown in Figure 99 relative to the baseline metal aircraft. The AR = 8 composite wing aircraft is slightly less productive than the all-composite aircraft due to lower payload. The AR = 10 composite wing aircraft, however, provides higher productivity than the all-composite aircraft over most of the mission range considered. This reflects the benefit of lower drag and increased wing span, particularly at low application rates where increased swath width is of greater value.

The reduction in payload with increasing wing weight becomes apparent for the AR = 12 aircraft. Reduced drag and greater wing span override the loss in payload only at low application rates.

Productivity in dry material missions is shown for the same cases in Figure 100. While the shapes of the curves are different, the overall comparison is approximately the same as for liquid missions. The AR = 10 composite wing aircraft is shown to have the best productivity over the entire range of missions.

Mission costs comparisons are given in Figure 101 for liquid missions and Figure 102 for dry missions. The data show that the AR = 10 composite wing aircraft has significantly better mission economics than the baseline metal aircraft in all missions. This configuration is also better than all of the other composite material configurations except in low liquid applications, where the AR = 12 composite wing aircraft has an advantage. The AR = 10 case appears to represent a near optimum trade-off of structural weight and airplane drag for agricultural aircraft in the size category of the AGB-3 airplane.

This investigation indicates that composite materials do offer worthwhile weight reduction benefits for agricultural aircraft. The most effective application appears to be the wing structure where the structural effi-

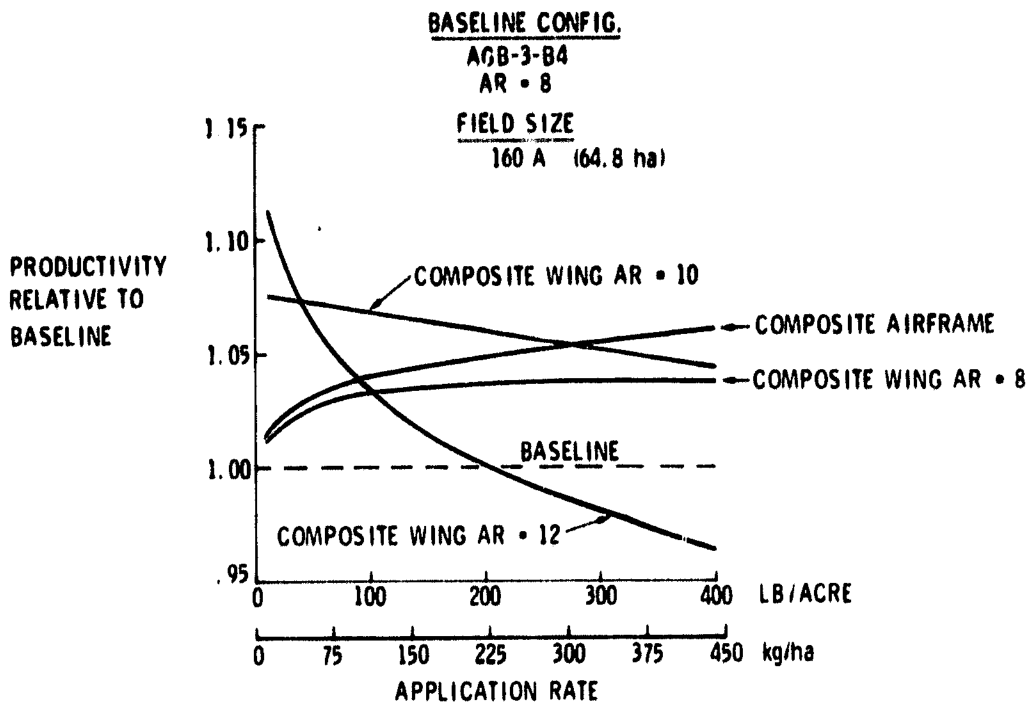


Figure 99 Composite Materials Configurations in Liquid Missions

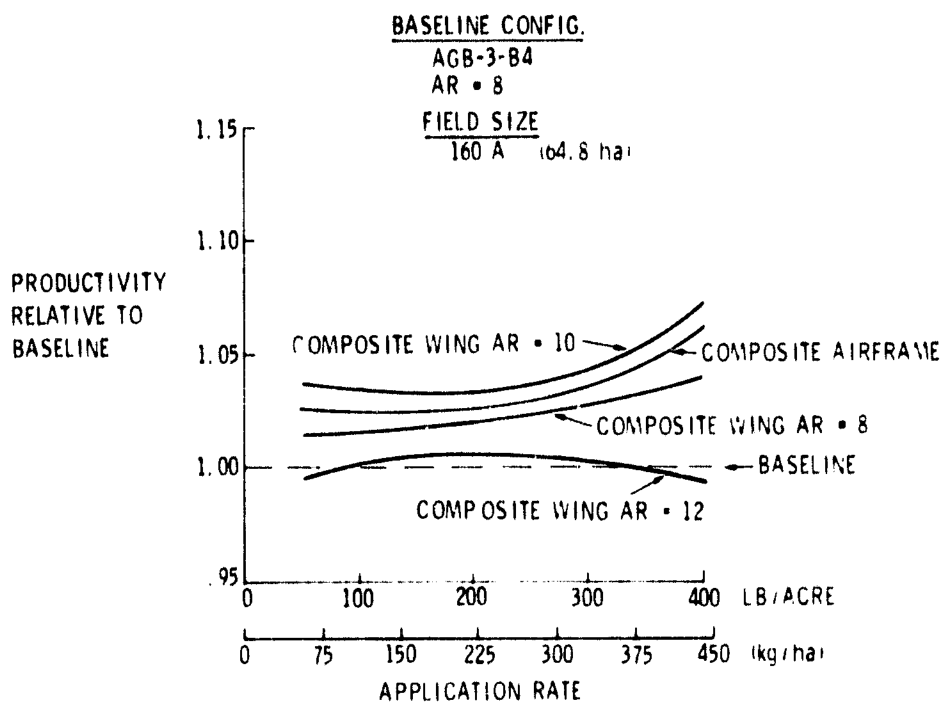


Figure 100. Composite Materials Configurations in Dry Missions

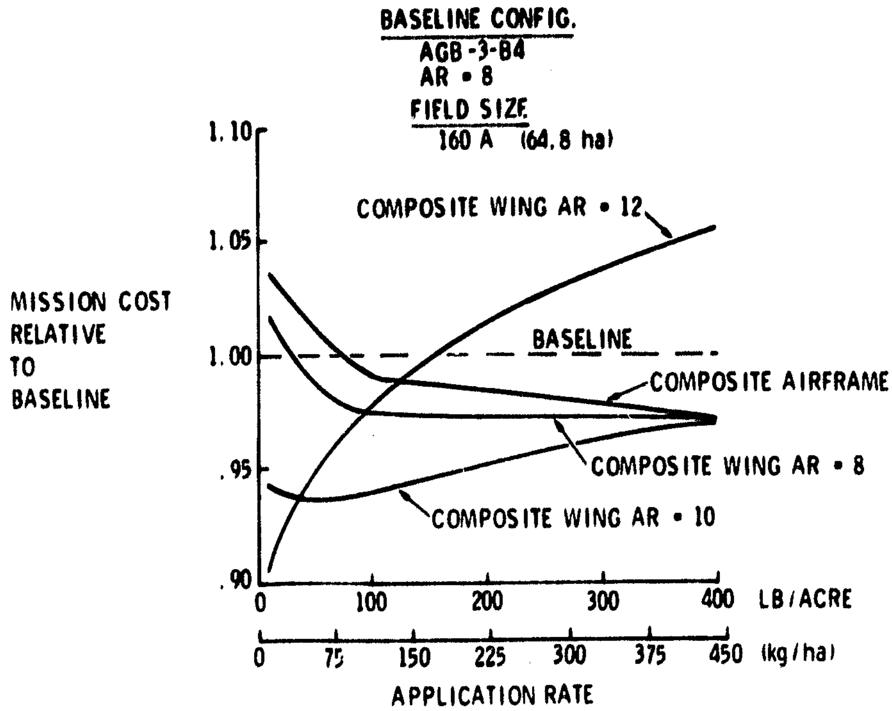


Figure 101. Composite Materials Configurations in Liquid Missions

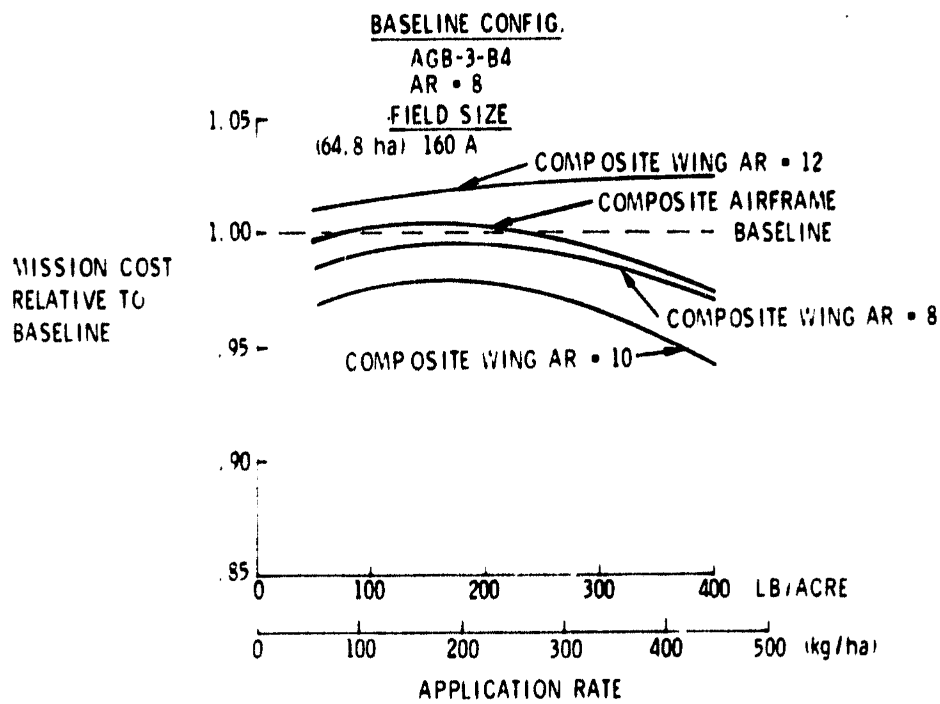


Figure 102. Composite Materials Configurations in Dry Missions

ciency of composite materials permits longer wings to provide the potential for wider swaths and lower induced drag.

The analyses described here do not include any potential benefits from corrosion reduction with composite materials. This subject is addressed qualitatively in the following section.

5.4 COMPOSITE MATERIALS FOR CORROSION REDUCTION

Many agricultural chemicals are highly corrosive to metallic structure, especially aluminum, and this is a major problem area within the agricultural aviation industry. While data are not immediately available on the full range of chemicals encountered, fertilizers may produce nitric acid, phosphoric acid, sulfuric acid, and numerous alkaline products which are corrosive to most metals. One of the most corrosive insecticides, Dibrom, hydrolizes into hydrochloric and hydrobromic acids. Information appears to be rather limited on corrosive products of insecticides, herbicides, and fungicides in combination with metals.

Resin matrix composite materials, by nature of the resin matrix, are naturally corrosion resistant. Current state-of-the-art in agricultural aircraft hoppers is fiberglass reinforced vinyl ester because of the corrosion resistant properties of this material. Also, the producers of Dibrom 14 report that fiberglass containers are now used for this material in lieu of stainless steel.

The epoxy resin composite materials considered in the present study for aircraft structural applications are considered to have strong potential for corrosion reduction. These materials are known to be more corrosion resistant than polyester resin materials, including the vinyl ester resin used in hoppers, because of properties of the epoxy resin. Selective applications of graphite, Kevlar and fiberglass/epoxy hybrid materials in high-corrosion areas may well be cost effective for retrofits to aircraft currently in service.

The selective use of composites for corrosion reduction in agricultural aircraft deserves further investigation regardless of weight-saving potential, and additional work in this area is recommended. As a first step, specific data are needed on the effects of the various agricultural chemicals on candidate composite materials. Little information is known to exist on this subject other than relating to fiberglass, and effort should be undertaken to develop a data base. This should include identification of the predominant chemical degradation products, a search for relevant data on chemical effects on composite materials, and testing to determine specific effects on candidate materials for aircraft structure.

Consideration should also be given to a field service test in which composite structure is installed in selected high-corrosion areas of current operational aircraft in normal application work. This concept was reviewed with the Advisory Committee, and the committee endorses a program of this type. The underside of the fuselage was identified as a primary corrosion area where skins fabricated of composite material might prove effective. It is recommended that plans be developed for a program to fabricate and service test composite belly skins for one or more current model aircraft.

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6.0 AIRCRAFT CONTROL SYSTEMS

6.1 STABILITY AND CONTROL CRITERIA

So far as can be determined within the scope of the present study, there are no standard design criteria presently available for stability and control characteristics of agricultural aircraft. Federal Aviation Regulations do not contain stability and control specifications for these aircraft; consequently, the aircraft are certificated to a combination of negotiated requirements and normal category requirements applicable to passenger-carrying aircraft. Data are lacking, however, to determine the specific handling qualities characteristics best suited to the dedicated agricultural mission in which the aircraft are constantly maneuvered at ground level with repeated sharp pull-ups, turns, and descents into the field. The aircraft require precise and rapid response to control inputs, and light stick forces are important for reduced pilot fatigue.

The lack of adequate design data in this area is a detriment to development of improved aircraft, and research is needed to fill this gap. The problem should be addressed from the point of view of the pilot/operator, with the objective of defining handling qualities that optimize productivity and safety in the dedicated mission. Flight tests and piloted simulations are needed for this purpose, including the possible use of a variable stability flight vehicle.

In the absence of existing design guidelines for stability and control characteristics, an effort was made in Lockheed's independent development program to evaluate the use of military requirements for design guidance. MIL-F-8785B, Flying Qualities of Piloted Airplanes (reference 28), provides criteria for various types of aircraft in different flight modes. The Class IV classification "high maneuverability airplanes" most closely fits agricultural aircraft, and dispersal operations would correspond to Flight Phase Category A for nonterminal flight phases requiring rapid maneuvering, precision tracking, or precise flight path control. Six current agricultural aircraft were evaluated against these military requirements using flying qualities estimates developed from aerodynamic and geometric data for these aircraft. Dimensions and areas were obtained by scaling photographs and three-views, hence the flying qualities estimates are approximations.

Longitudinal short-period frequency data are shown in Figure 103 relative to the military requirements. Level 1 requirements are considered to be applicable to agricultural aircraft, with degradation to Level 2 or 3 in case of failure. The current aircraft are indicated as being near the lower boundary, which may be relaxed if direct lift control is provided. For longitudinal short-period damping, all of the aircraft were found to fall well within the acceptable boundaries, and only three of the aircraft meet or exceed the minimum dutch roll frequency requirements. Roll-mode constants for all aircraft are well within the specified limit.

Bank angle capability for all of the aircraft falls short of the military requirements of 90° in 1.3 seconds, but this requirement is considered overly severe and could probably be relaxed to about 60° for agricultural aircraft. Pilot opinion in this area is strongly influenced by stick forces, and pilot work would be needed to determine the acceptable combination of bank angle and stick forces. Roll performance data are given in Figure 104, which shows that all of the aircraft fall near the unsatisfactory boundary, but this requirement may also be too demanding for agricultural aircraft.

Stick forces were not evaluated. The military stick force requirements are not considered suitable for agricultural aircraft. Pilot tests are needed to ascertain acceptable lower limits on stick forces without the tendency for pilot induced oscillations.

The initial baseline aircraft configurations selected for the current study were also evaluated against the military criteria. The baseline aircraft compare favorably with the current aircraft in most cases and meet most of the military criteria. The large baseline aircraft is indicated as having lower bank angle and roll performance capability than the current aircraft, but this evaluation is based on nominal assumptions of control surfaces and mission conditions. More detailed analyses would be necessary for configuration refinement.

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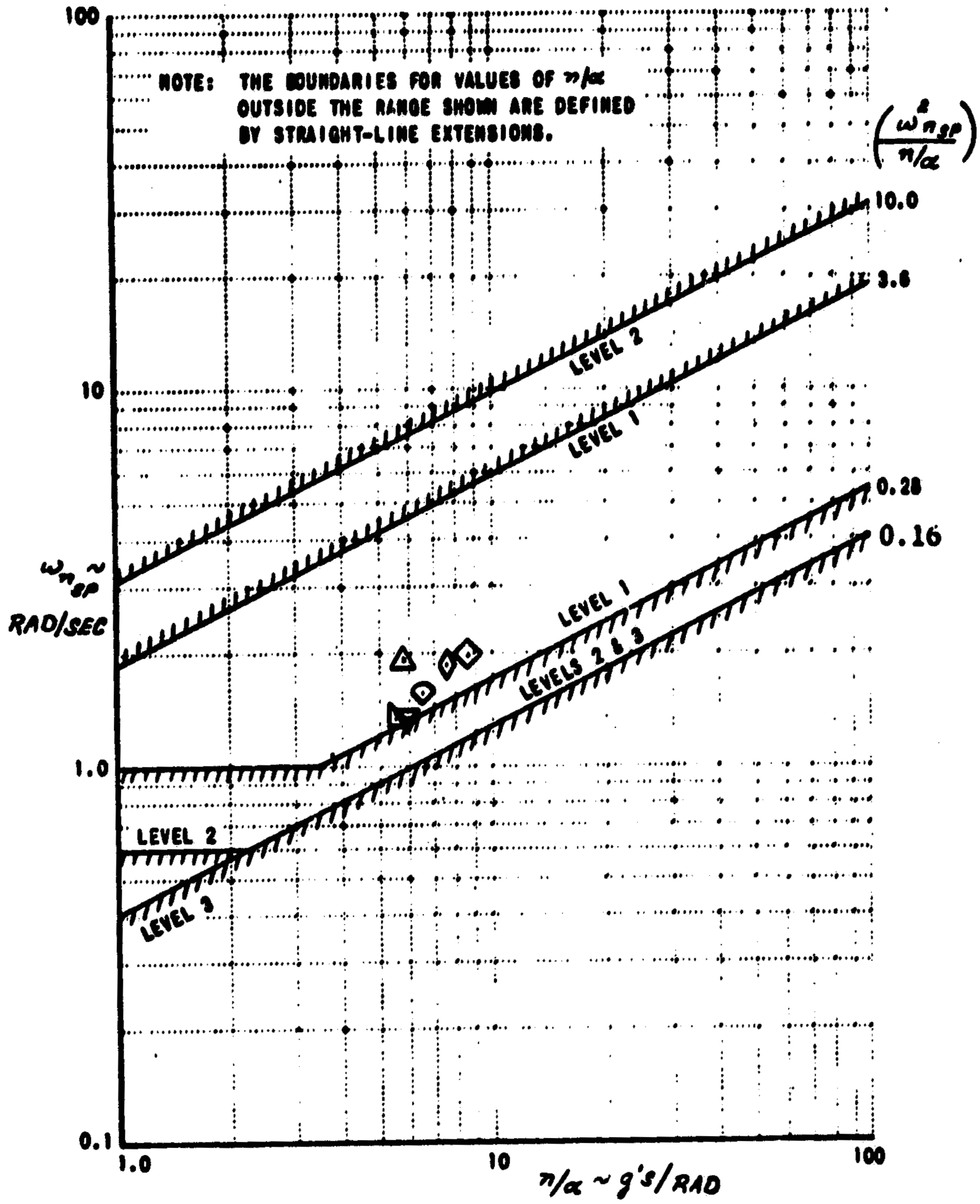

Figure 103. Current Aircraft Longitudinal Short Period Frequency Characteristics

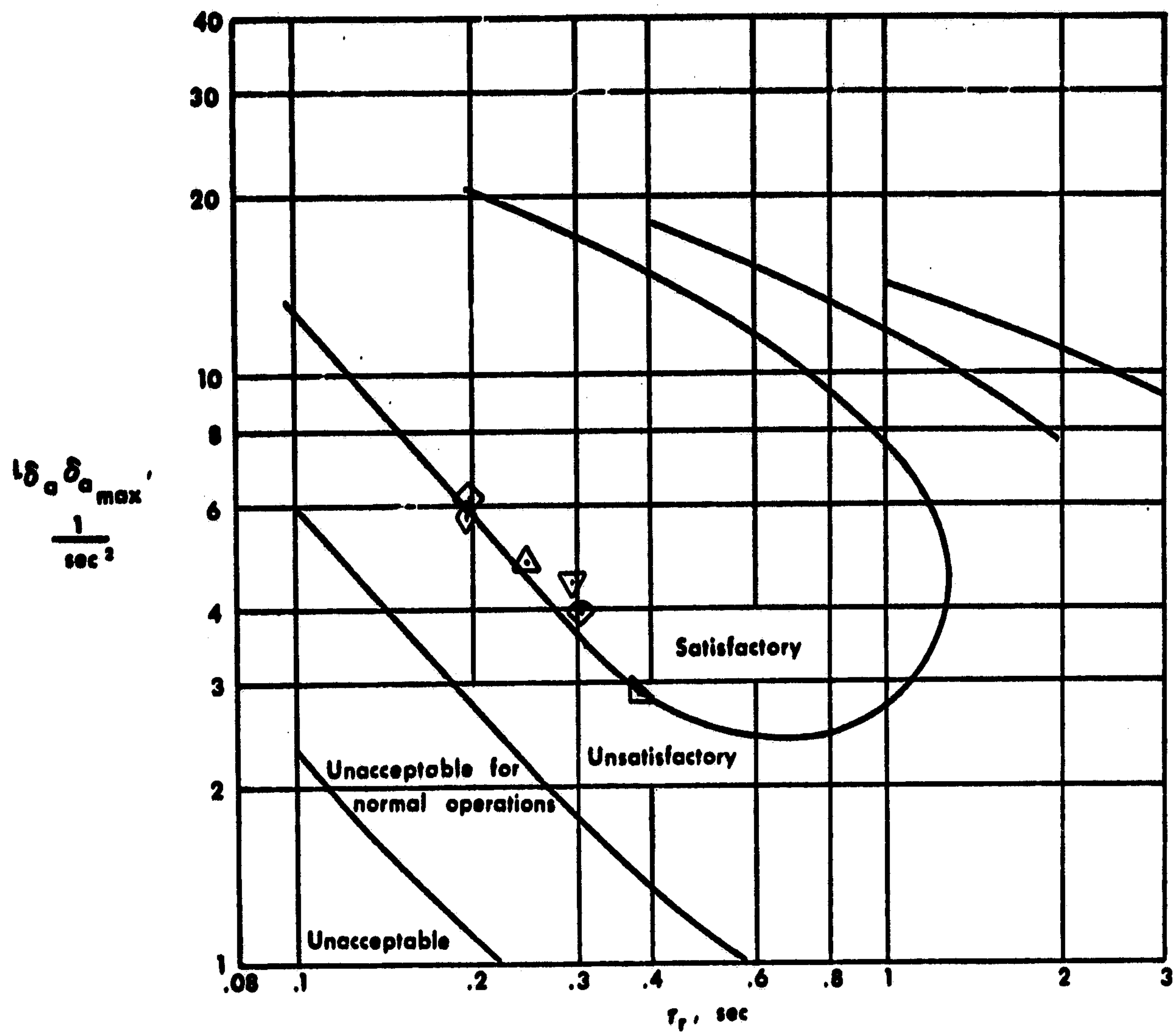

Figure 104. Current Aircraft Roll Performance

6.2 AIRCRAFT CONTROL SYSTEM CONCEPTS

The two baseline aircraft chosen in this study are sufficiently small to utilize fully mechanical control systems. Conventional ailerons would provide adequate control power for both baseline designs. The smaller baseline design would probably require a radius nose overhang balance with a small horn balance which will also serve for mass balancing to provide the desired low lateral stick forces. Thirty percent chord aileons with spans of 40 percent located between the 60% wing span station and the wing tip were assumed for the small aircraft.

The larger baseline agricultural aircraft design will require 30 percent chord ailerons with spans of 50% on the outboard half of the wing to provide roll control capabilities approaching those of the smaller baseline design. A sealed overhang balance and horn balance, also used for mass balancing, would be required to reduce the lateral stick forces to the level required for good handling qualities. A geared tab on the large ailerons may also be used to reduce the lateral stick forces if necessary.

The 40 percent chord full-span rudder assumed for each of the baseline designs may also require some degree of aerodynamic balance. The horn used for mass balancing with a simple radius nose may be adequate to provide reasonable pedal forces for the smaller baseline design. The large baseline aircraft may require more sophisticated aerodynamic balances such as geared tabs and/or sealed overhang balances.

The assumed elevators for both of the baseline designs are also 40 percent chord full span control surfaces. Aerodynamic balances may consist of unsealed radius nose, sealed overhang, horn, or geared tab singularly or in combinations as required.

Neither of the two baseline aircraft is large enough to justify powered control systems. Suitable power packages are available, however, if boosted or fully powered systems are desired. System redundancy or mechanical system back up would be required to assure fail safe operation with powered systems.

The outstanding advantage of the fully powered irreversible control system is the capability of tailoring the stick/pedal forces to those required for optimum handling qualities. The boosted power control system is a compromise in that the basic force variations are similar to the fully mechanical system but with reduced force levels required at the stick and rudder pedals.

6.3 DIRECT FORCE CONTROL CONCEPTS

6.3.1 Direct Lift Control

Of the three direct force controls, direct lift is easiest to implement and for agricultural applications is probably the most useful and desirable. In the simplest case, high lift flaps may be used as the primary force generator.

Flaps are particularly desirable in agricultural aircraft for reduced take-off distance. Operations are regularly conducted at forward load points with short unpaved runways, and the necessity to reduce payload to achieve takeoff can have a severe detrimental effect on mission economics. Figure 105 shows the effects of 60% and 100% span flaps in reducing takeoff distance for the initial baseline study aircraft.

Flaps are also beneficial in reducing turn time. Figure 106 shows the improvement in mission productivity and cost obtained from reduced turn time with use of flaps on the small baseline aircraft in a representative mission. Average turn time was reduced by about 1.5 seconds with 60% flaps at 20° and by 2.5 seconds with 100% flaps at 20°.

Figure 107 presents the incremental load factor available from the flap system used as a direct lift control as a function of flap deflection based on a maximum incremental lift coefficient from the flaps of 0.50. The track speed for computing the load factors is 120 knots which is representative of the smaller baseline agricultural aircraft. The data are also indicative of the capabilities of the larger baseline design since the

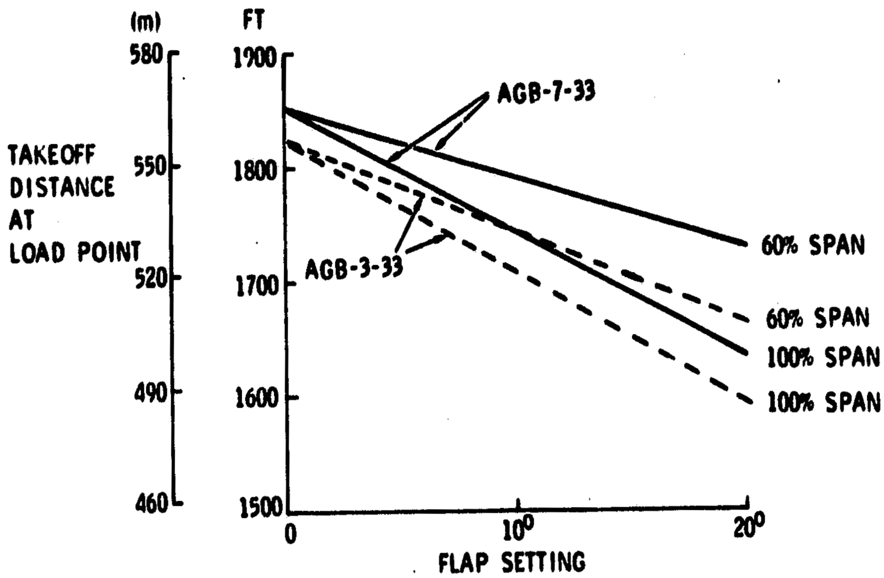

Figure 105. Effects of Flaps on Takeoff Distance

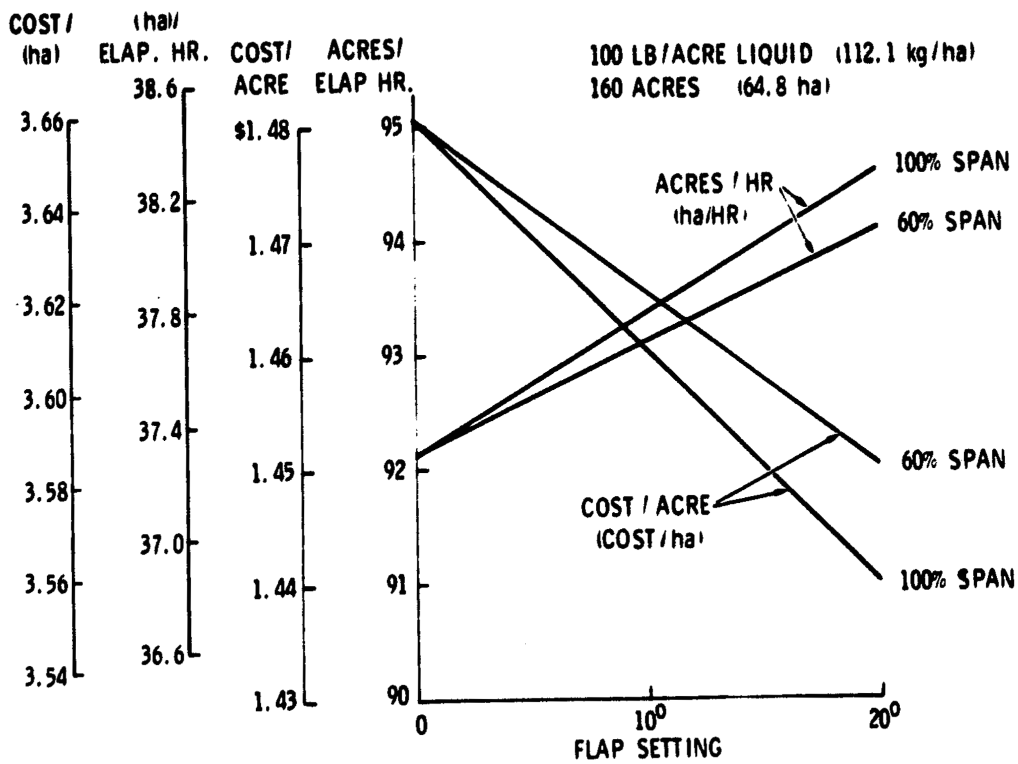

Figure 106. Effects of Flaps (AGB-3-33)

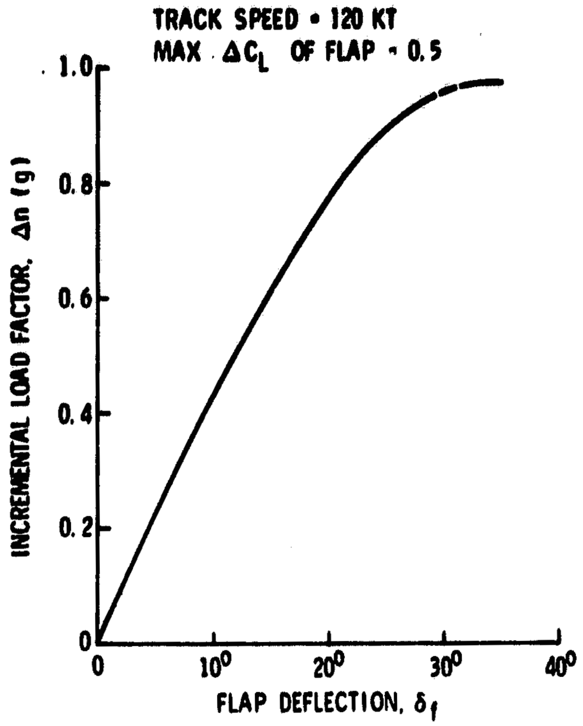

Figure 107. Direct Lift Control Effectiveness

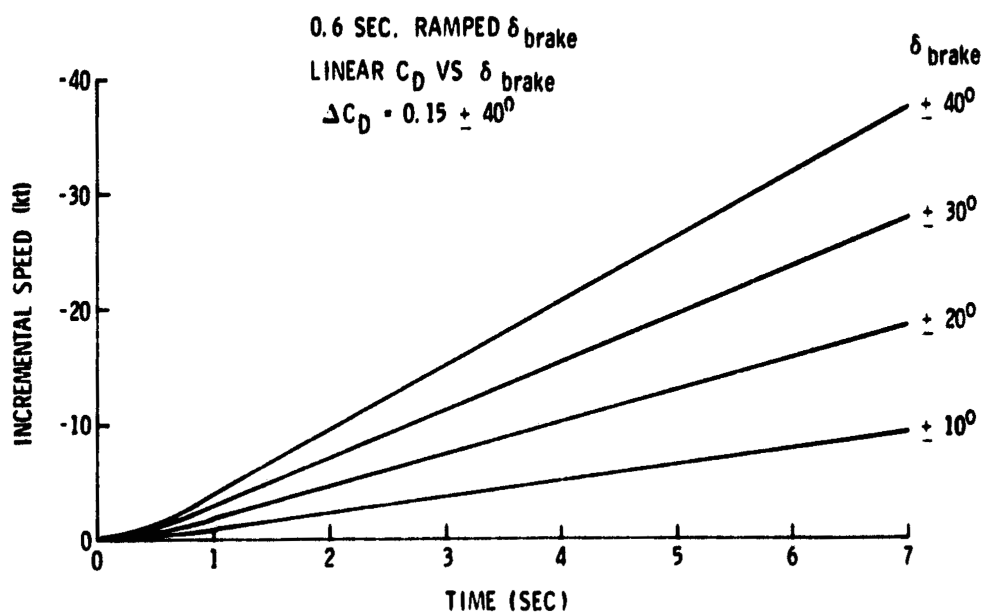

Figure 108. Direct Drag Control

flap system produces a lower incremental lift coefficient but operates at a higher track speed.

Use of flaps for direct lift control is more desirable than the use of a spoiler system. In general, a spoiler system is not required for other applications for agricultural aircraft in the size and speed ranges of this study. In order to provide positive incremental load factors the spoilers would have to be uprigged for neutral direct lift control inputs, thus producing additional drag at this design point.

The most promising control for the direct lift system is integration with the longitudinal function of the stick. A clutching arrangement would be used to incorporate direct lift control for the mechanical control systems visualized in this study. Boosted or irreversible powered control systems would only require an additional input to the power packages.

The flap system evaluation was reviewed with the Advisory Committee, and committee members strongly recommend that flaps be included in future aircraft designs.

6.3.2 Direct Drag Control

Direct drag control could be useful to the maneuvering of agricultural aircraft in that the drag change with such a system is very responsive and permits speed changes without use of throttle changes. Direct drag control in combination with direct lift control provides a possible means for further reduction in turn time, but this was not evaluated quantitatively. The direct lift control system alone provides a degree of direct drag control in that the direct lift generator also produces additional drag from both profile and lift induced drag.

Figure 108 shows the capability of a direct drag control system to provide speed change as a function of time using a drag brake deflected to the angles shown at the end of a 0.6 second ramp. The brake is capable of providing an incremental drag coefficient of 0.15 with ± 40 degree deflections. For this figure, drag coefficient is assumed to vary linearly with deflection. No attempt was made to define the size or type of drag brake required to provide the drag coefficient used. Ideally the drag brake will produce only drag changes without changes in lift or pitching moment. Split flaps and/or ailerons with balanced upper and lower deflectable surfaces may be used or drag devices may be added at the wing tips or on the fuselage.

Control of the direct drag control system would probably be provided through fore and aft movement of the throttle quadrant or an associated additional lever located with the throttle controls. Although other control methods could be devised, fore and aft motion of the "throttle hand" would be the most natural means of controlling the longitudinal forces on the aircraft.

The possible merits of a drag control device such as a drag brake were discussed with the Advisory Committee. It was noted by the committee that this capability might offer some advantage for slowing the aircraft for initial descent into the field from a high-speed approach. With turboprop engines, however, the capability is immediately available through propeller pitch change. It has not been possible in the present study to establish a clear justification for direct drag control.

6.3.3 Direct Sideforce Control

Direct sideforce control is potentially useful in agricultural operations to provide straight ground tracks under cross-wind conditions without banking or excessive yawing. The capabilty might also be of value in maneuvering around field obstacles and for clean-up passes around the field borders.

Figure 109 shows the sideforce required to provide an unbanked and unyawed straight track along the ground as a function of cross wind for a typical aircraft with a track speed of 120 knots. Figure 110 gives the rudder deflection required for sideforce control to balance the aircraft over the range of cross winds shown. The horsepowers shown in Figure 111 are required to overcome the drag of the device used to balance yawing moments

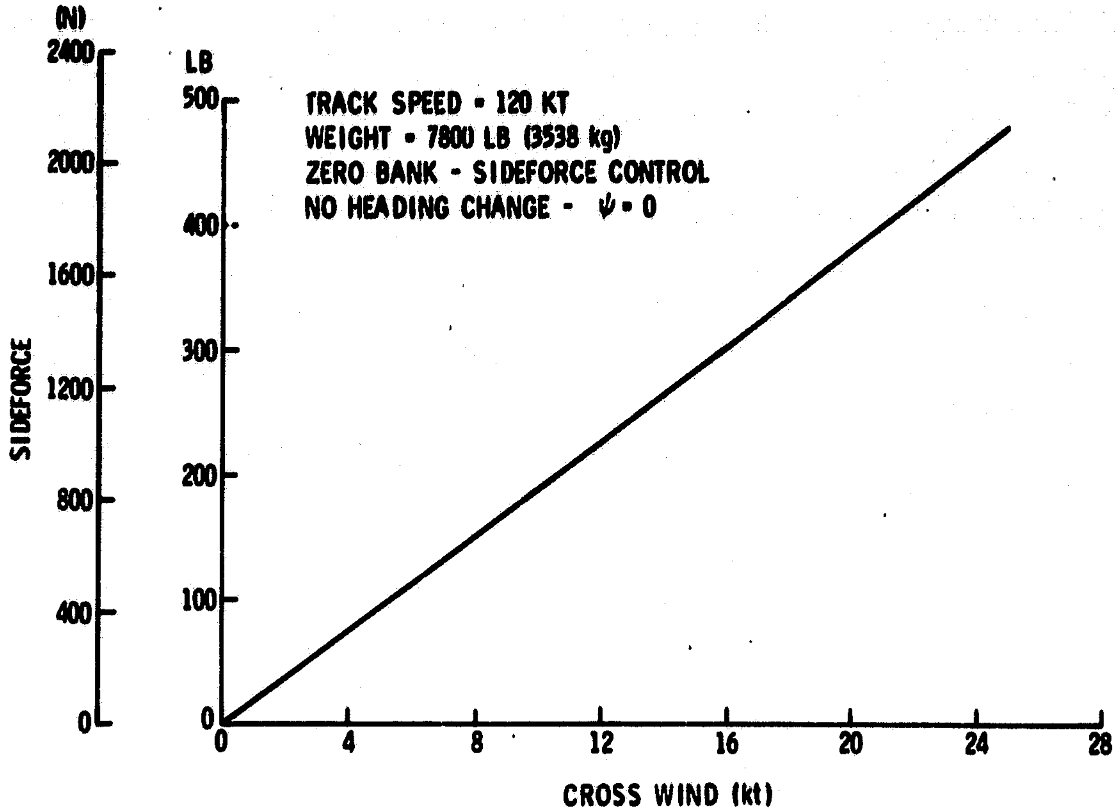

Figure 109. Sideforce Due to Cross Wind

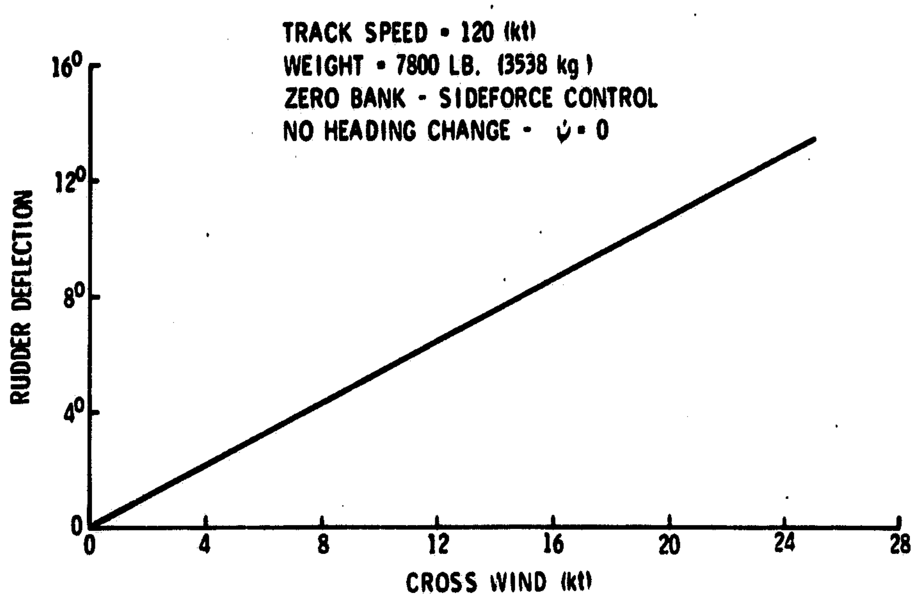

Figure 110. Rudder Required for Sideforce Control

of the rudder. The drag-producing devices in this case are assumed to be located at aileron midspan. These devices may be utilized for both direct drag control when used symmetrically and yawing moment control in conjunction with the rudder when used individually. The horsepower required for this function appears to be somewhat prohibitive.

Other methods of direct sideforce control generation may use sideforce producing surfaces on the fuselage or symmetrically at the wing tips. The drag produced by either of these will be much less than the system utilizing the rudder. Fuselage mounted surfaces may be restricted by the ground clearances or interference with material hopper access.

A typical lateral maneuver with wings level is presented in Figure 112 using direct sideforce control at a maximum value of 559 pounds for the smaller baseline aircraft. The equivalent sideforce coefficient is 0.04 which may be generated by any of the direct sideforce generating systems being considered. At a swath speed of 120 knots, the longitudinal distance travelled during a reasonable lateral displacement and return to the original swath appears to be prohibitively large.

One means of cockpit control for the direct sideforce control system is lateral movement of the throttle quadrant. This type of cockpit control would be best suited for a fully powered irreversible control system but could also be used for the unpowered or power boosted control sytem. There are other methods of integrating the direct sideforce control of the primary stick, but these are not as attractive as the side motion of the throttle quadrant since the direct sideforce control would be mixing to some extent with the lateral control.

The possible value of direct side force control was reviewed with the Advisory Committee. Committee members expressed the view that there is no great need for this capability and incorporation of such a system would introduce undesirable complexities into the aircraft. Since the engineering evaluation indicates marginal performance capability, the study conclusion is that direct side force control is not justified for agricultural aircraft designs in the near future.

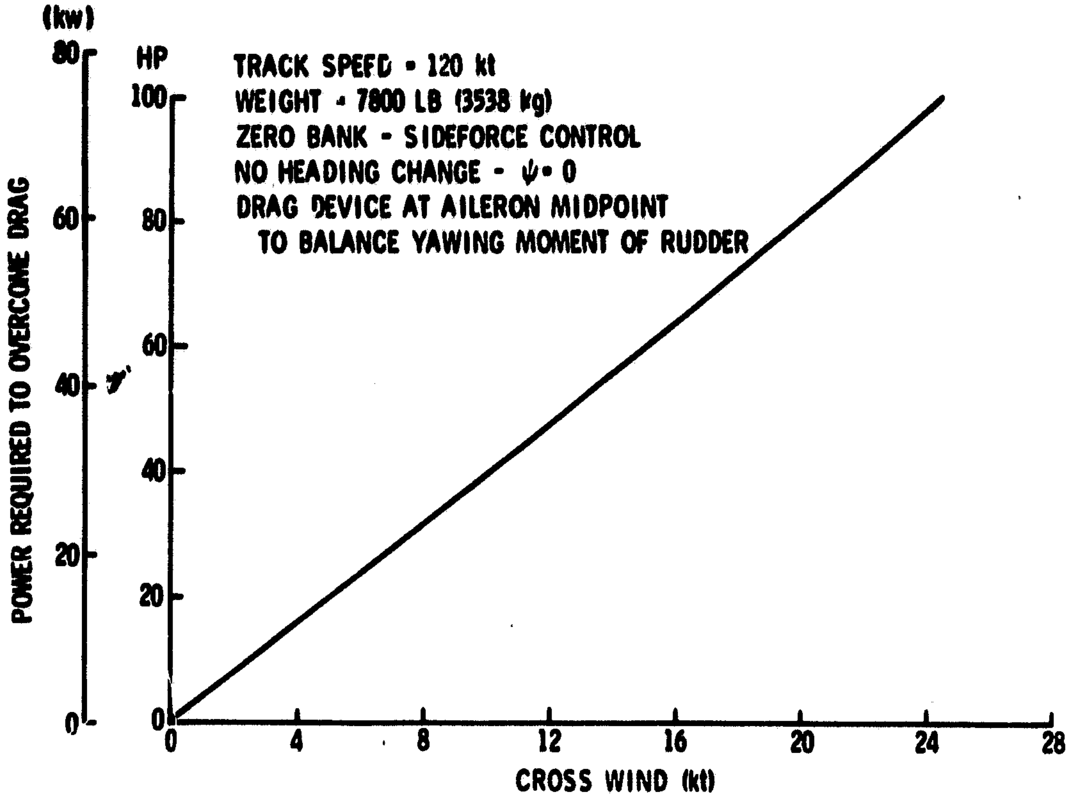

Figure 111. Horsepower to Balance Sideforce Control System Drag

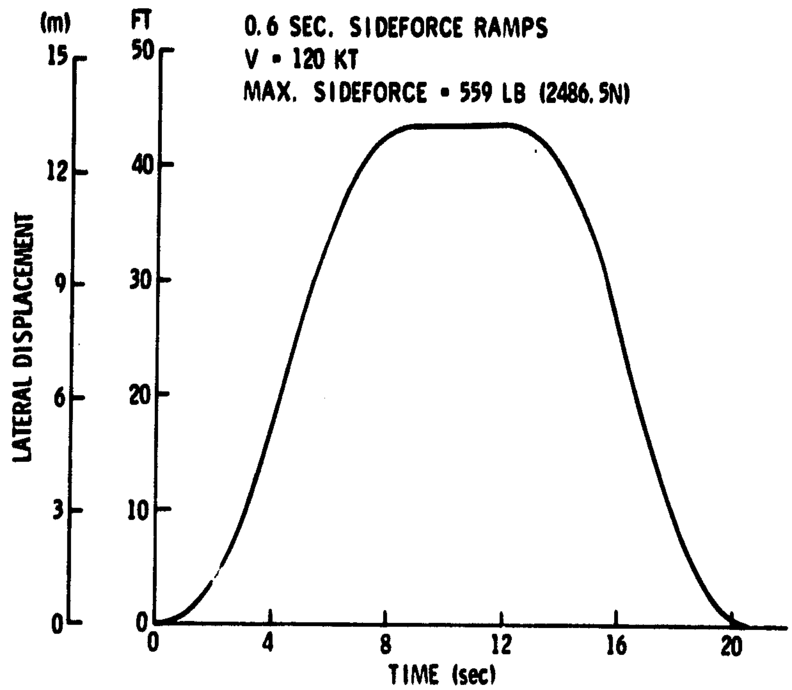

Figure 112. Typical Lateral Maneuver Using Sideforce Control

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7.0 MISSION ANALYSIS

7.1 MISSION PRODUCTIVITY AND COST DATA

Mission productivity and cost analyses were performed throughout the study in the evaluation of aircraft configurations, as noted in preceding sections of this report. This section presents productivity and cost data for the refined baseline configurations over a wide range of missions. These data were generated with the operations research model using aircraft performance and cost estimates for the final refined AGB-3-B4 and AGB-7-B1 configurations.

The primary mission parameters that are varied in the present analyses are field size and application rate. Other mission parameters are held constant for all cases. The basic operation is defined as utilizing a home base and seven forward load points, with six fields to be treated at each load point. All fields are defined to be the same size in a given case. Load point ferry distance is 25 miles (40 km) and field ferry distance is 8 miles (13 km) from the load point. The load point runway is assumed to be a grass strip with surface friction coefficient of .08.

Figures 113 through 115 contain the mission productivity data for the AGB-3-B4 airplane, covering both liquid and dry missions. Figures 116 through 119 contain the mission cost data for the same mission spectrum, including the variation in mission cost with field size for several application rates. Figures 120 through 122 contain the mission productivity data and Figures 123 through 126 the cost data for the AGB-7-B1 airplane. All dry material cases are based on the use of conventional dry material spreaders.

It should be noted that a portion of the mission spectrum is labeled "declining swath width" in cases of liquid missions in the cost data figures. At approximately 430 lb/acre (482 kg/ha) application rate, the AGB-3 aircraft can no longer maintain the maximum swath width and fly at the minimum allowed swath speed. This is due to the increasing power required for material dispersal as the application rate increases. At this point

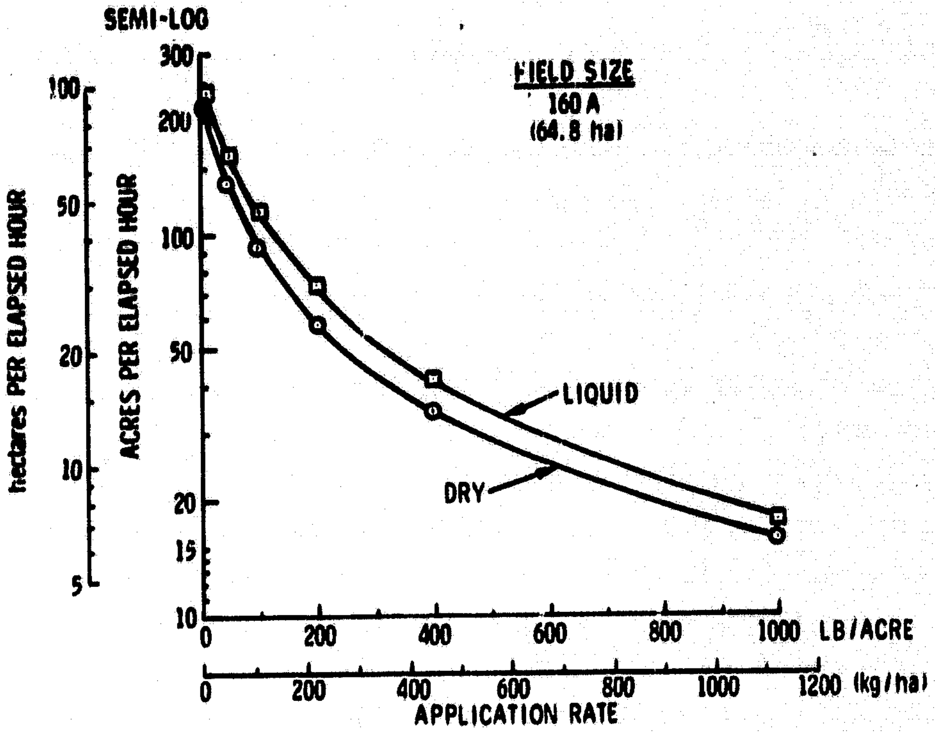

Figure 113. AGB-3-B4 Mission Productivity

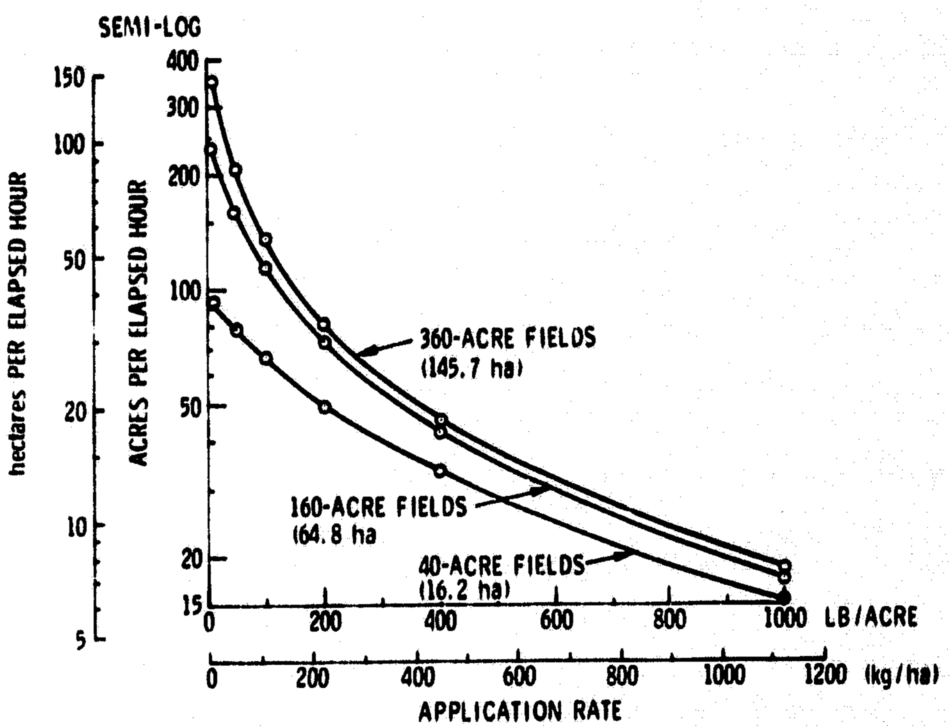

Figure 114. AGB-3-B4 Mission Productivity (Liquid)

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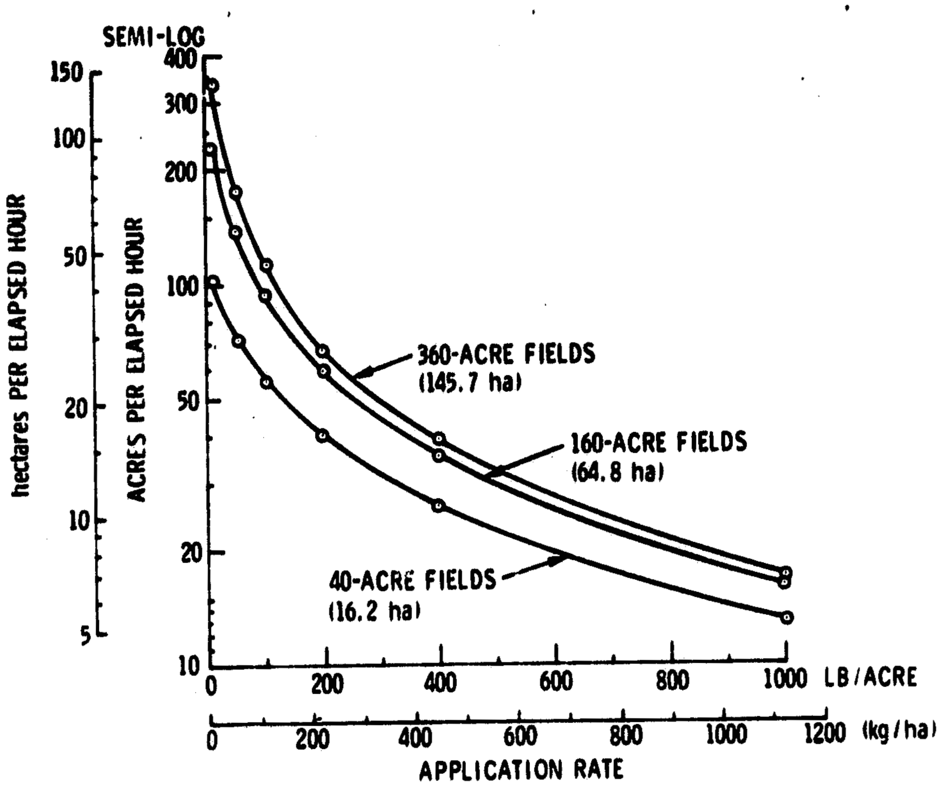

Figure 115. AGB-3-B4 Mission Productivity (Dry Material)

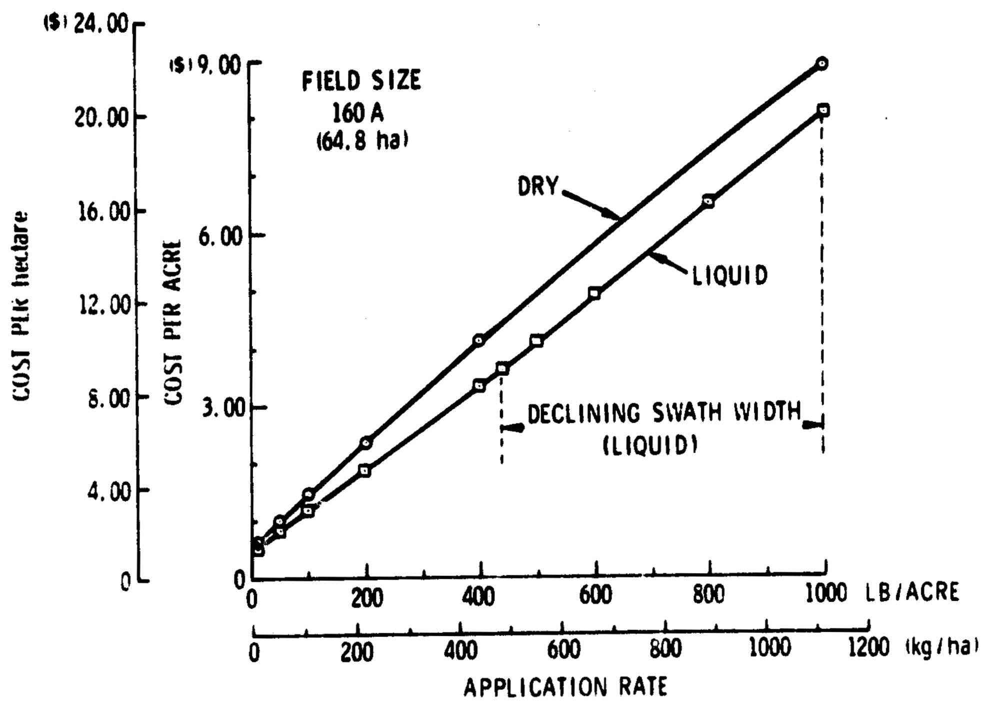

Figure 116. AGB-3-B4 Mission Costs

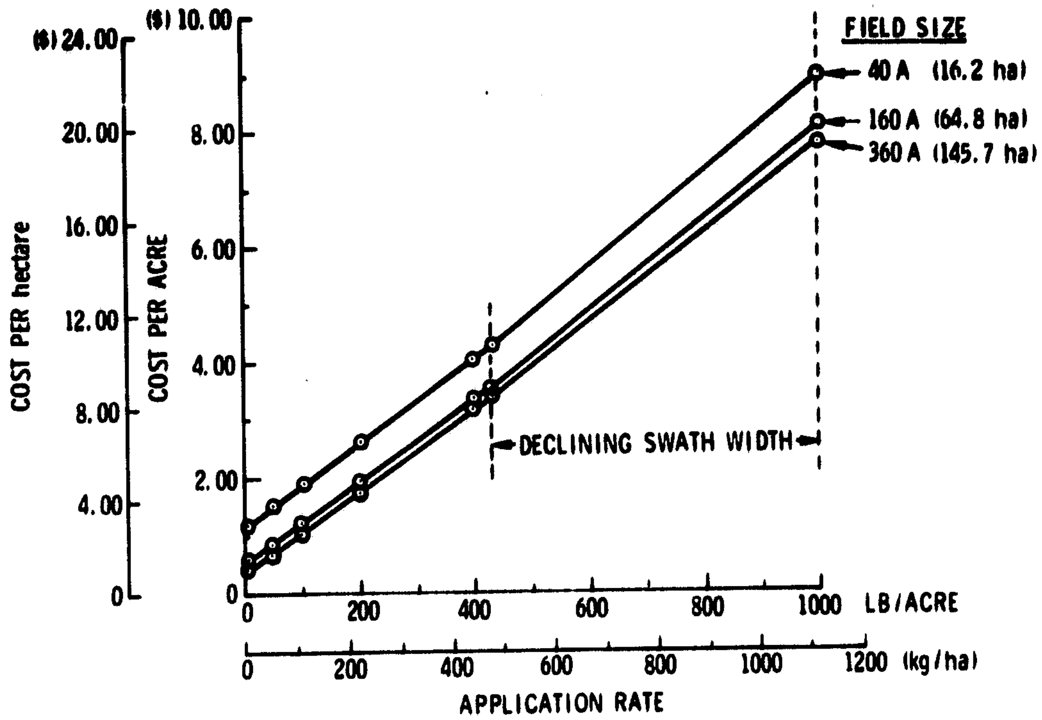

Figure 117. AGB-3-B4 Mission Costs (Liquid)

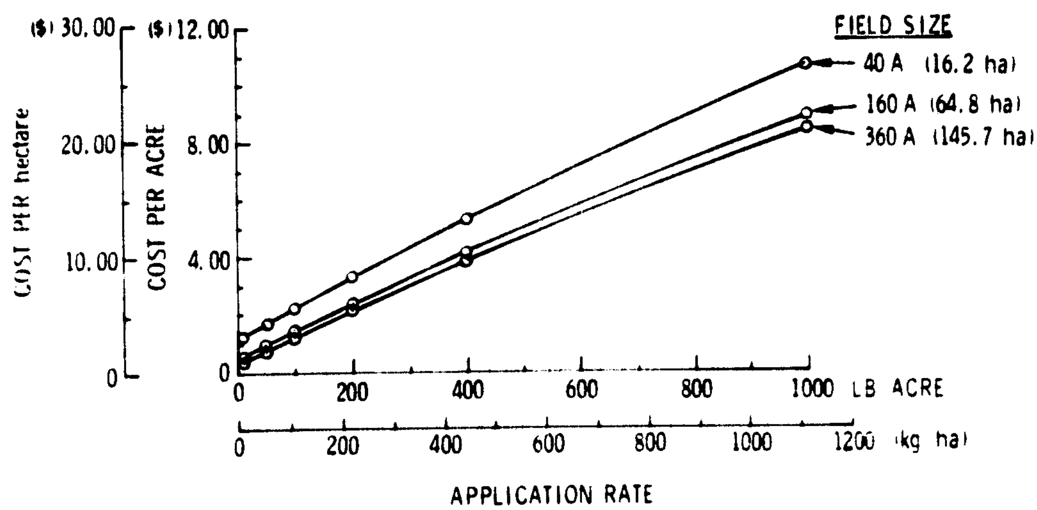

Figure 118. AGB-3-B4 Mission Costs (Dry Material)

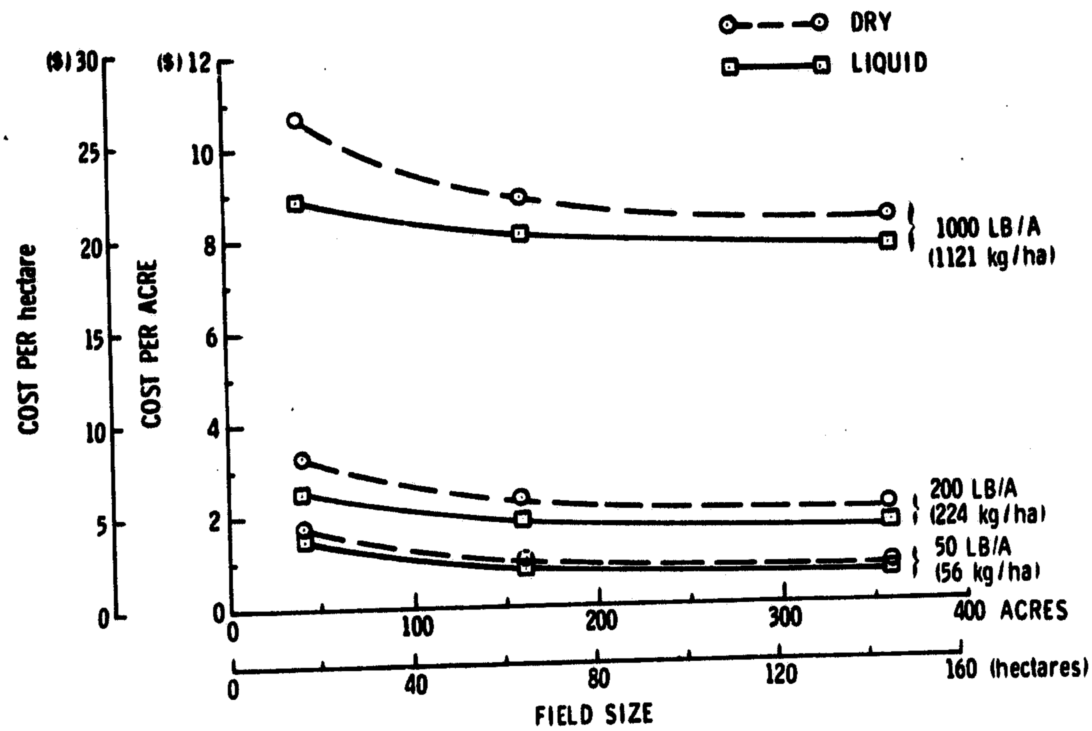

Figure 119. Mission Cost vs. Field Size (AGB-3-B4)

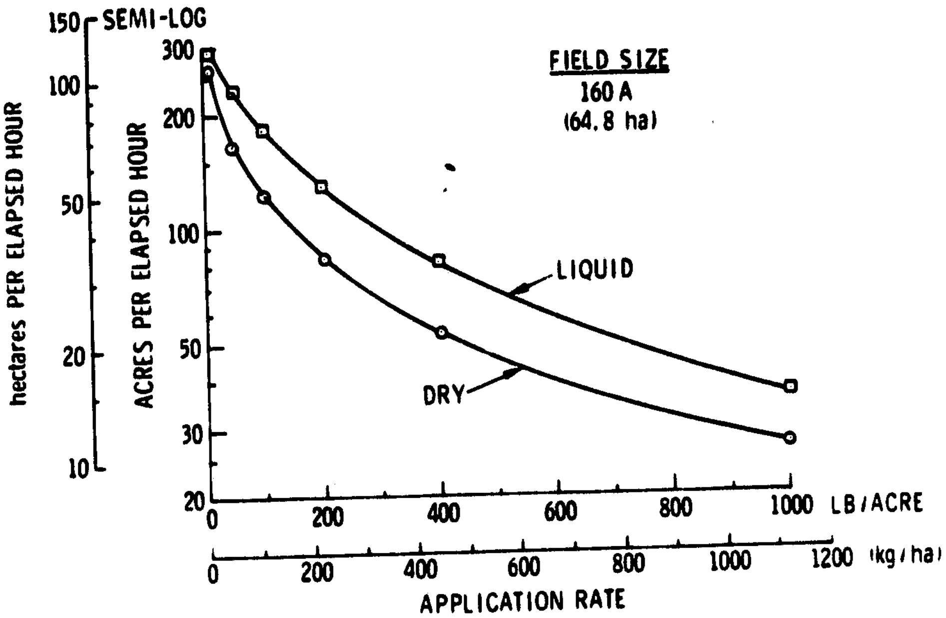

Figure 120. AGB-7-B1 Mission Productivity

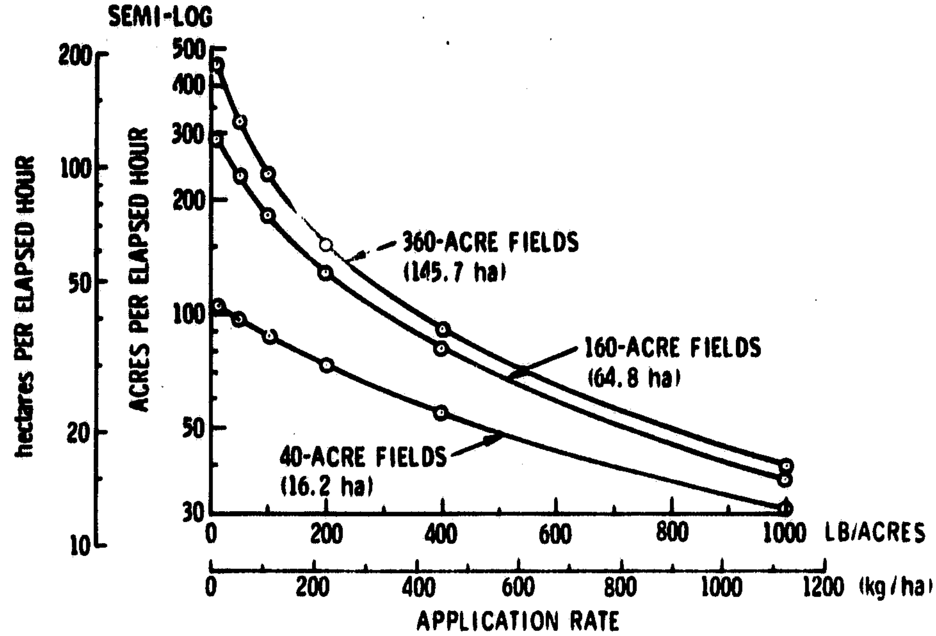

Figure 121. AGB-7-B1 Mission Productivity (Liquid)

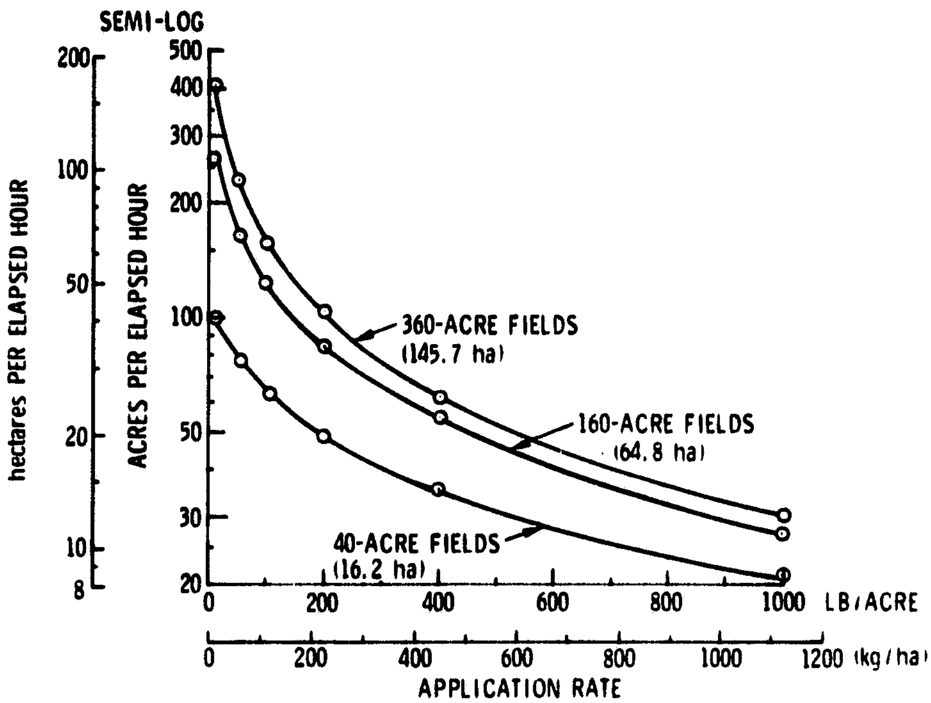

Figure 122. AGB-7-B1 Mission Productivity (Dry Material)

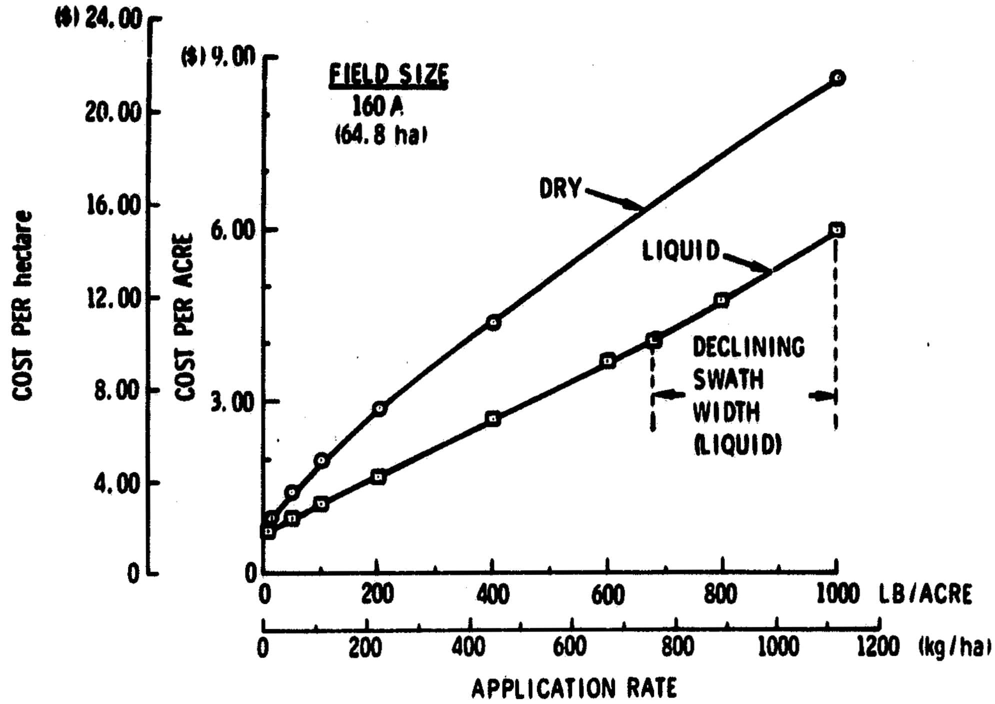

Figure 123. AGB-7-B1 Mission Costs

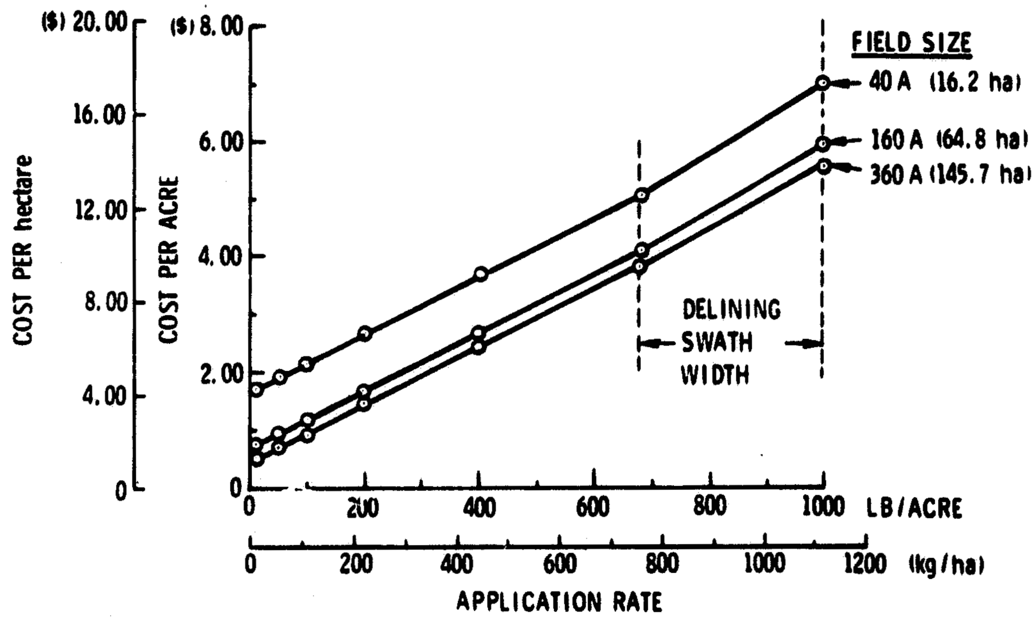

Figure 124. AGB-7-B1 Mission Costs (Liquid)

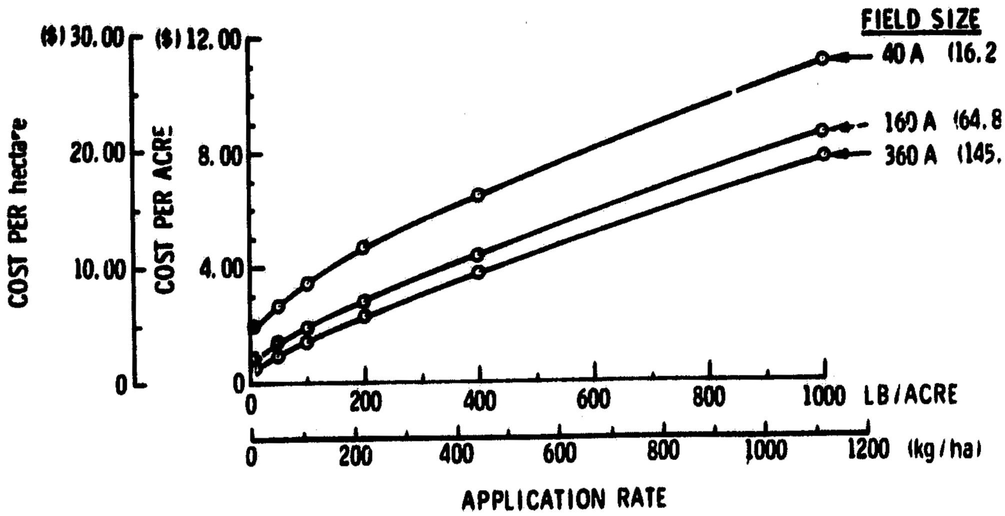

Figure 125. AGB-7-B1 Mission Costs (Dry Material)

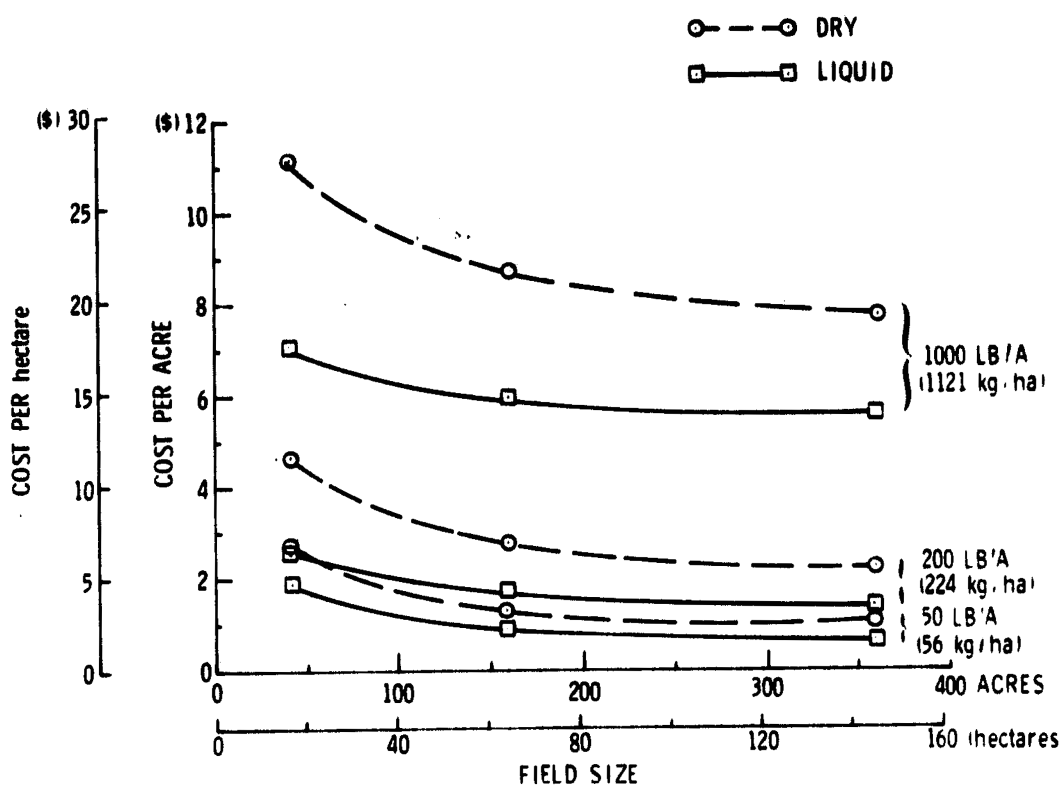

Figure 126. Mission Cost vs. Field Size (AGB-7-B1)

the swath width is reduced so as to maintain adequate power for flight, and swath width continues to reduce as application rate increases. This causes the cost per unit area treated to increase at a slightly higher rate. This effect occurs for the AGB-7 airplane at approximately 680 lb/acre (762 kg/ha).

Figures 127 and 128 show mission productivity data for the AGB-7 airplane relative to the AGB-3 airplane. Figures 129 and 130 show the corresponding comparison for mission costs.

From these comparison data, it can be seen that the large aircraft is much more productive than the small aircraft. Due to higher operating costs, however, the large aircraft is more economical only at higher application rates. In the case of liquid operations the large aircraft is quite attractive above application rates of approximately 100 lb/acre (112 kg/ha) for larger fields. However, there are few liquid missions of this type being performed with aircraft today. If high-application liquid missions become available on a large scale, such as liquid fertilizer work, the large aircraft would be more cost effective than the small aircraft for these missions.

For dry material operations, the large aircraft shows a mission cost advantage over the small aircraft only for extremely high application missions which are basically non-existent today. This poor showing is probably attributable to the high drag characteristics of conventional dry material spreaders assumed in the dry material cases for both aircraft. Spreader drag significantly reduces the productivity advantage that otherwise accrue with the larger size aircraft. Consequently, the smaller aircraft is more cost effective for dry materials over the practical range of available missions. This relationship might change in favor of the larger aircraft if more efficient means of dry material dispersal can be developed.

It was not possible in the present study to examine wide area missions such as forest fertilizing and pest control. The large aircraft may well be more attractive in those type missions. It is recommended that further

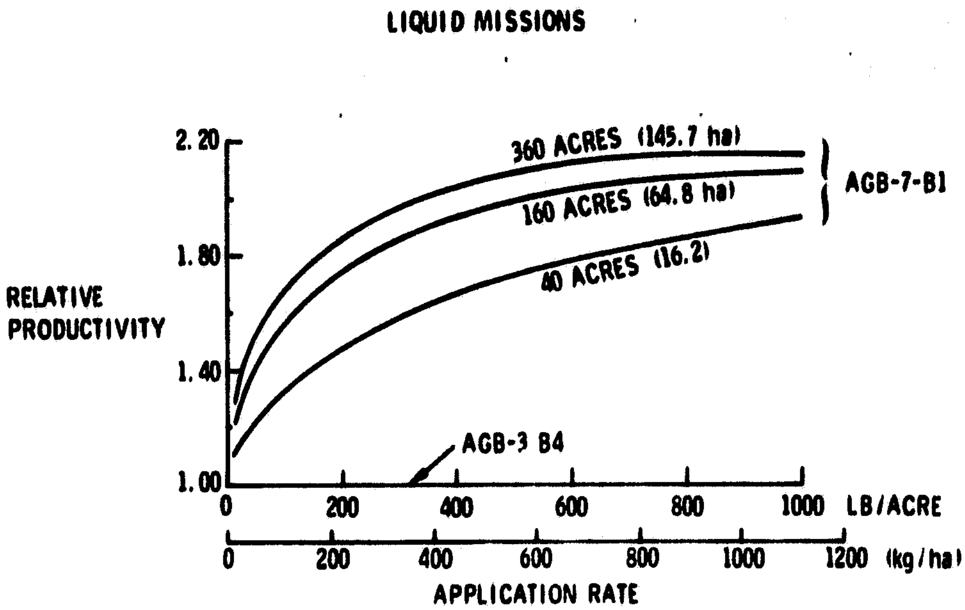

Figure 127. Comparison of AGB-7 and AGB-3 Mission Productivity

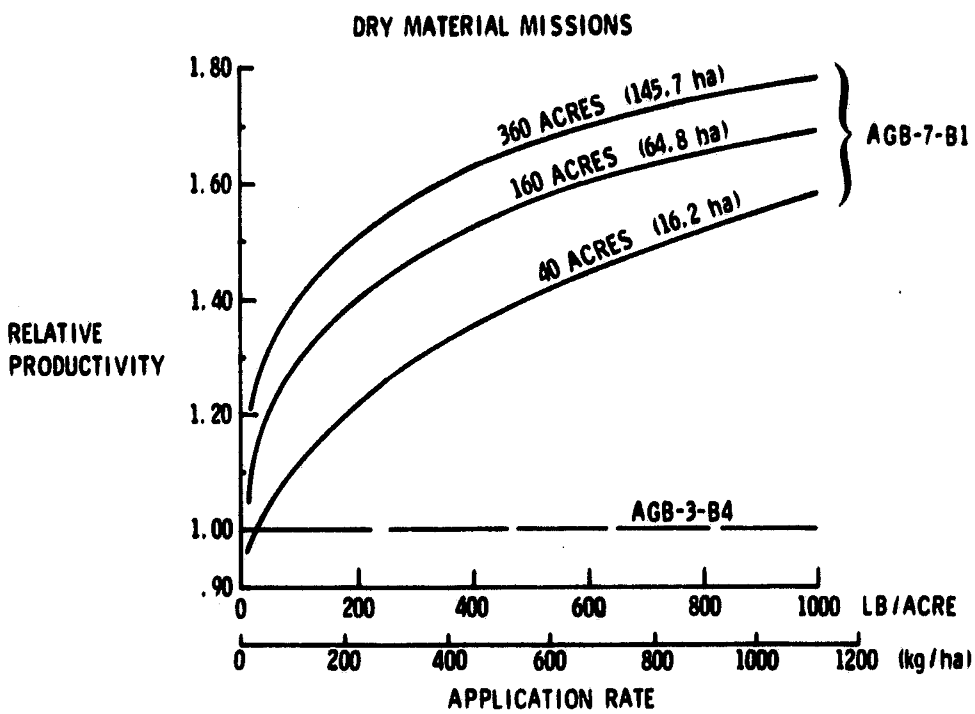

Figure 128. Comparison of AGB-7 and AGB-3 Mission Productivity

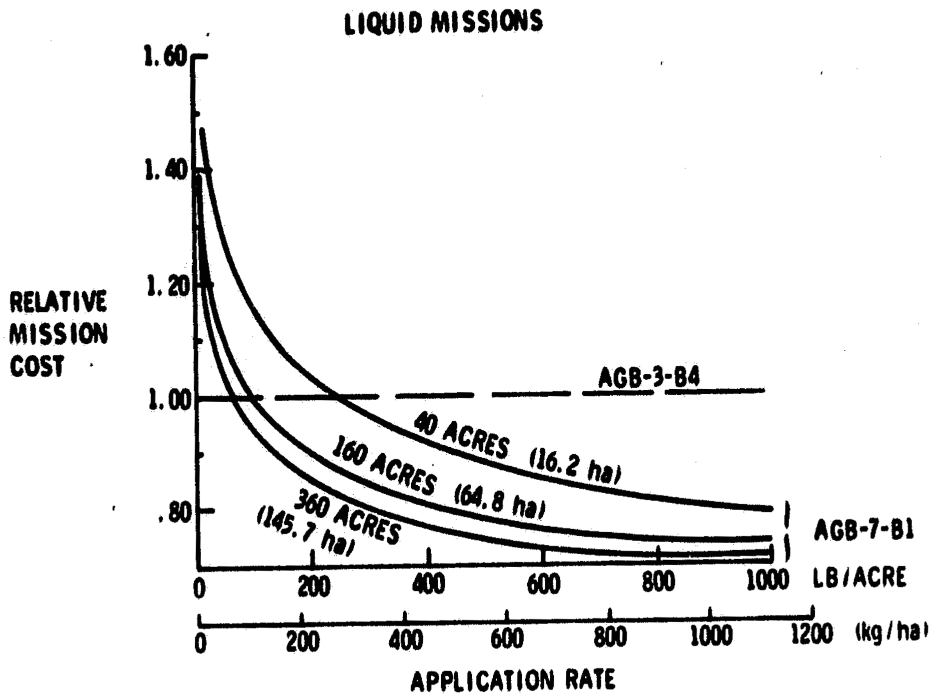

Figure 129. Comparison of AGB-7 and AGB-3 Mission Cost

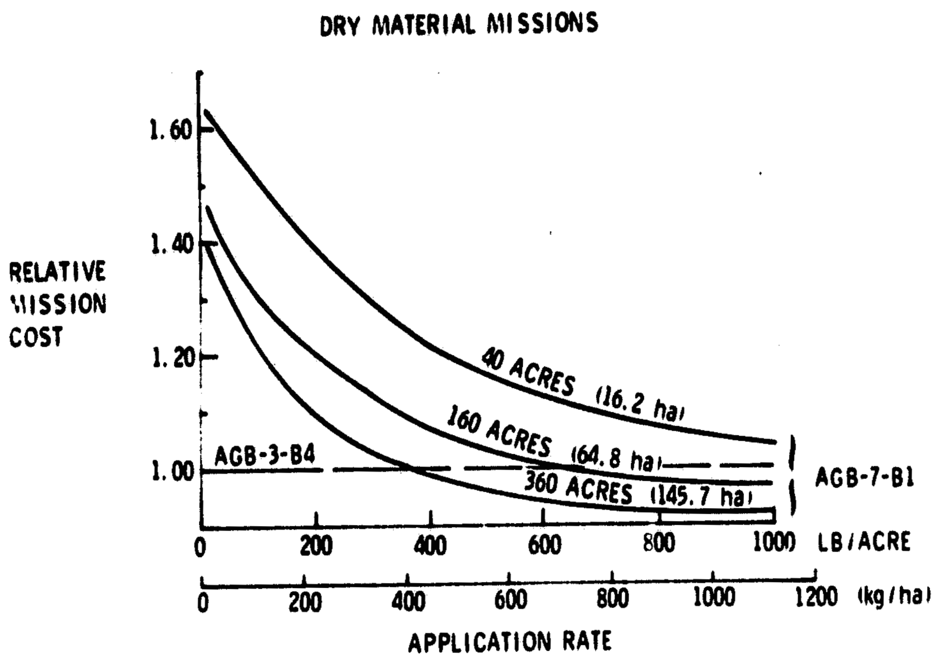

Figure 130. Comparison of AGB-7 and AGB-3 Mission Cost

analyses be conducted of wide-area missions to evaluate the relative merits of large versus small aircraft.

7.2 OPERATIONAL TRADE-OFF DATA

A number of different operational cases were run with the operations analysis model for the refined baseline configurations to develop trade-off data for varying operating conditions. These data are as follows.

Hot Day and Altitude Effects - Figures 131 and 132 show the effects of hot day operations and 5000' (1524 m) operations on mission cost. These cases assume unlimited runway length, and increased costs are due to degraded aircraft flying performance due to thrust degradation.

Runway Length - Figure 133 shows the effects of load-point runway length on takeoff payload for standard, hot day, and altitude conditions. These data are based on a grass runway with surface frition coefficient of .08.

Runway Surface Friction - Figure 134 shows the effects of runway surface friction on takeoff distance. Data are plotted over a range of friction coefficients from paved surfaces to long grass surfaces.

Payload Reduction - Figures 135 and 136 show the effects on mission cost of reducing payload below the maximum design payload for representative missions. These data reflect cases in which payload must be reduced to achieve takeoff.

Gross Weight Takeoff Distance - Figures 137 and 138 show takeoff distance for a range of aircraft gross weights. CAM 8 recommended gross weight limits are indicated for both aircraft. These data apply to a grass runway with friction coefficient of .08.

Field Ferry Distance - Figures 139 and 140 show the effects of varying field ferry distances on aircraft productivity and mission cost. Ferry distance is the straight-line distance from the load point to the field being treated.

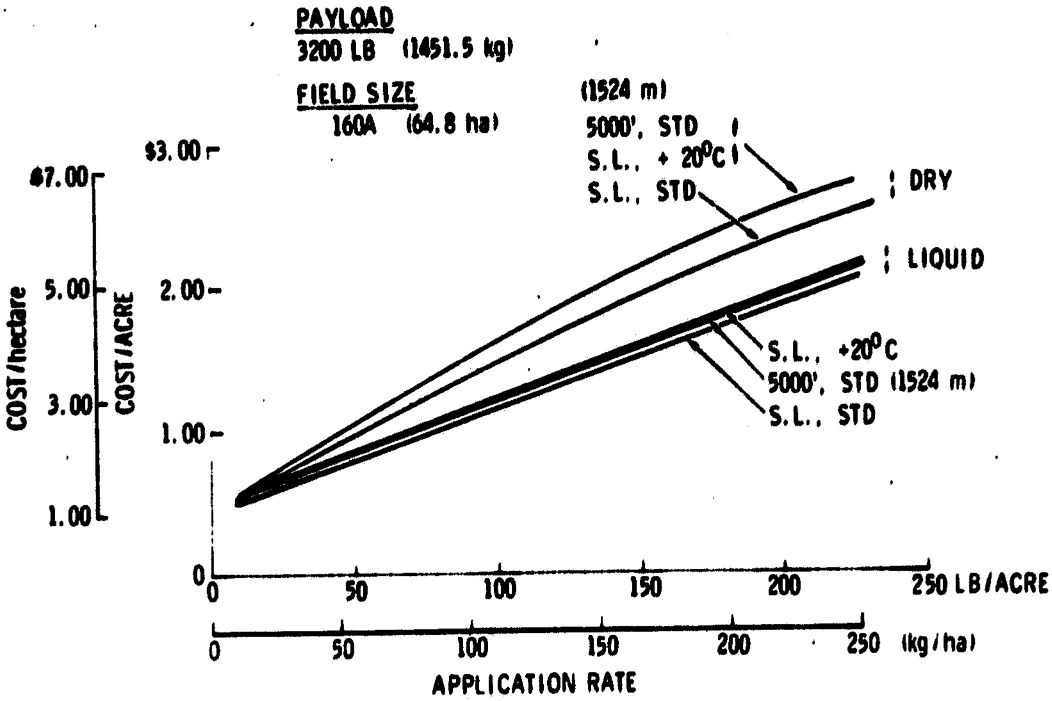

Figure 131. Hot Day & Altitude Effects (AGB-3-B4)

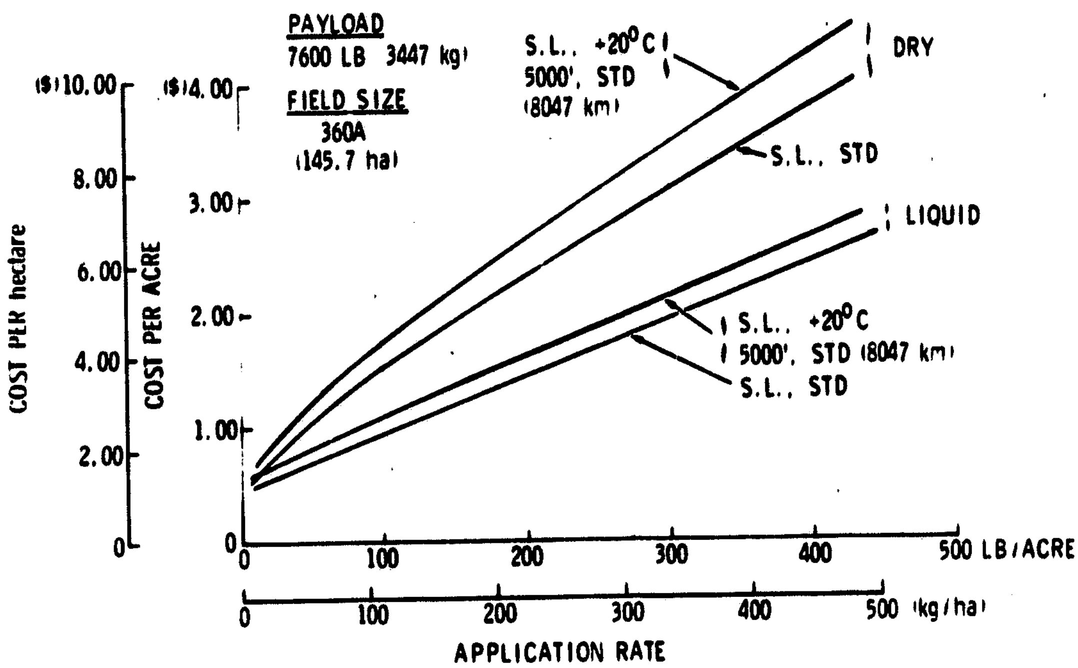

Figure 132. Hot Day & Altitude Effects (AGB-7-B1)

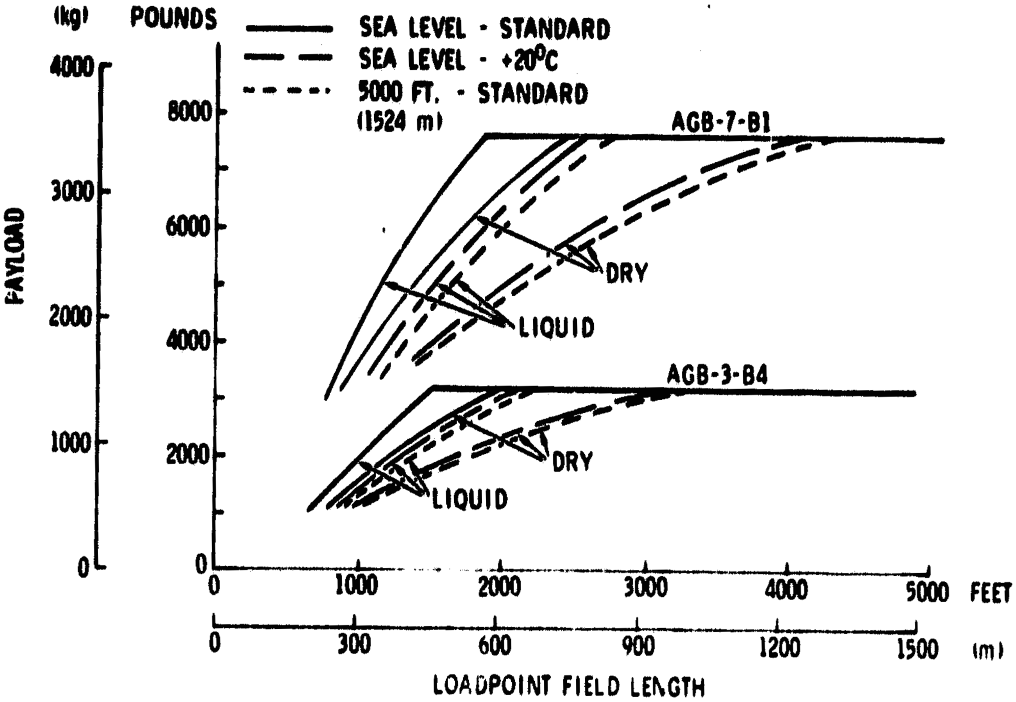

Figure 133. Effects of Runway Length on Payload

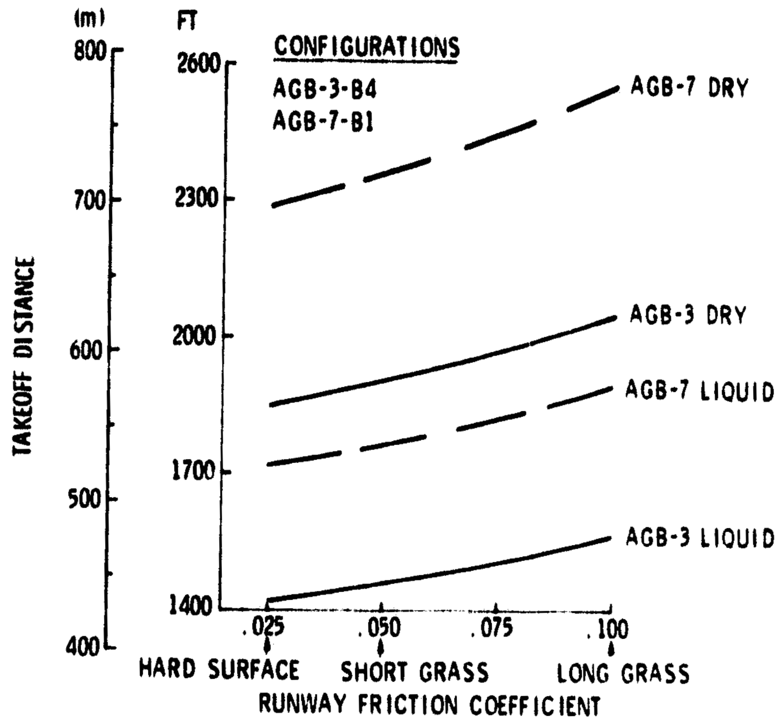

Figure 134. Effects of Runway Surface Friction on Takeoff Distance

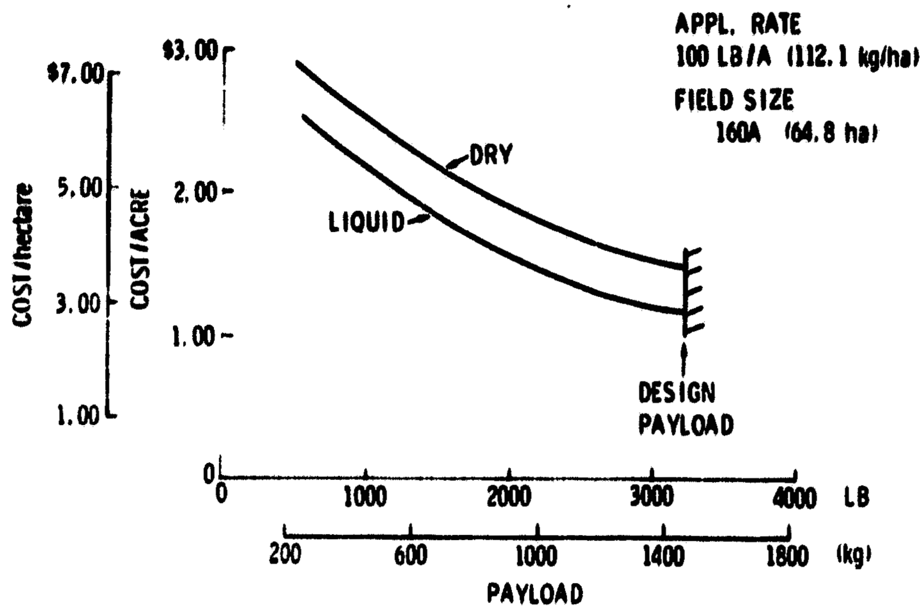

Figure 135. Effects of Payload Reduction (AGB-3-B4)

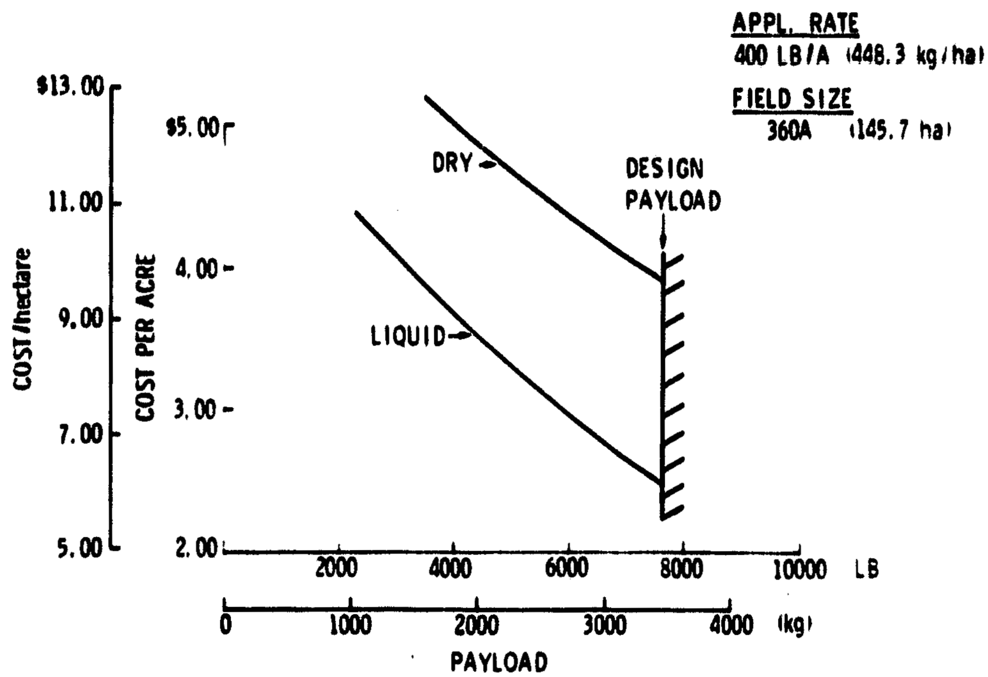

Figure 136. Effects of Payload Reduction (AGB-7-B1)

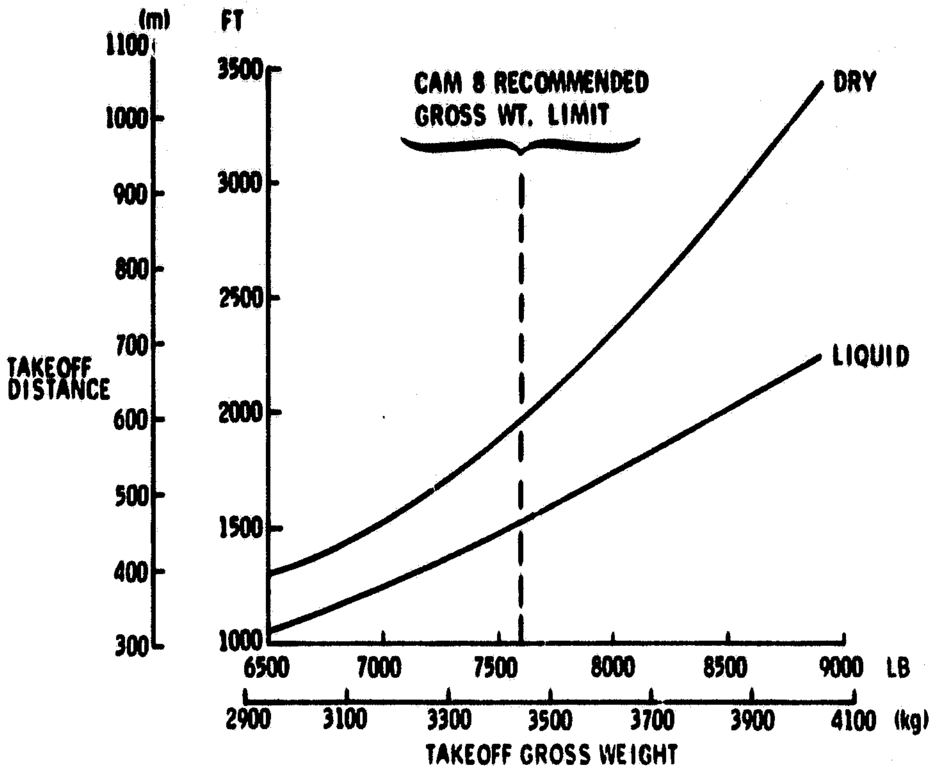

Figure 137. Gross Weight Takeoff Distance (AGB-3-B4)

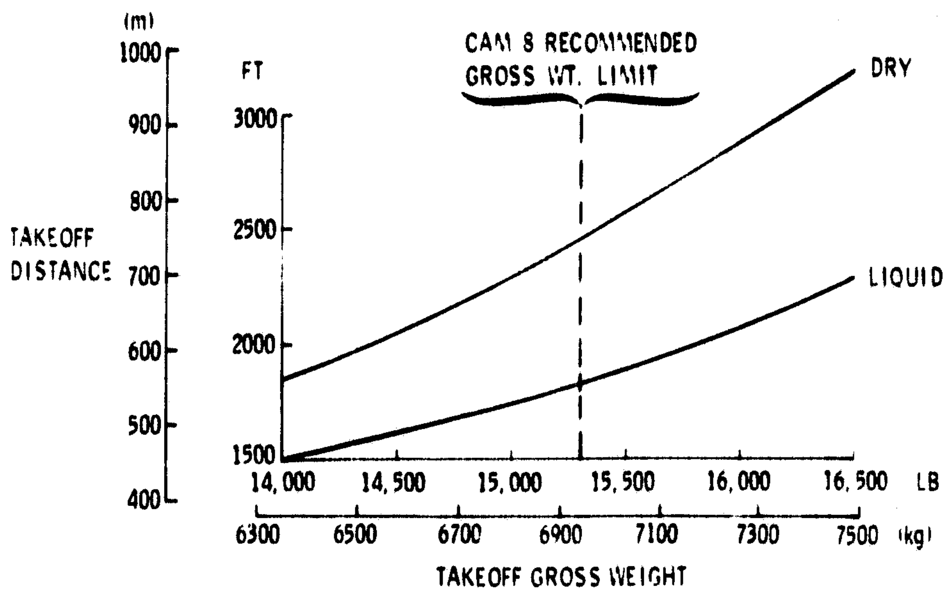

Figure 138. Gross Weight Takeoff Distance (AGB-7-B1)

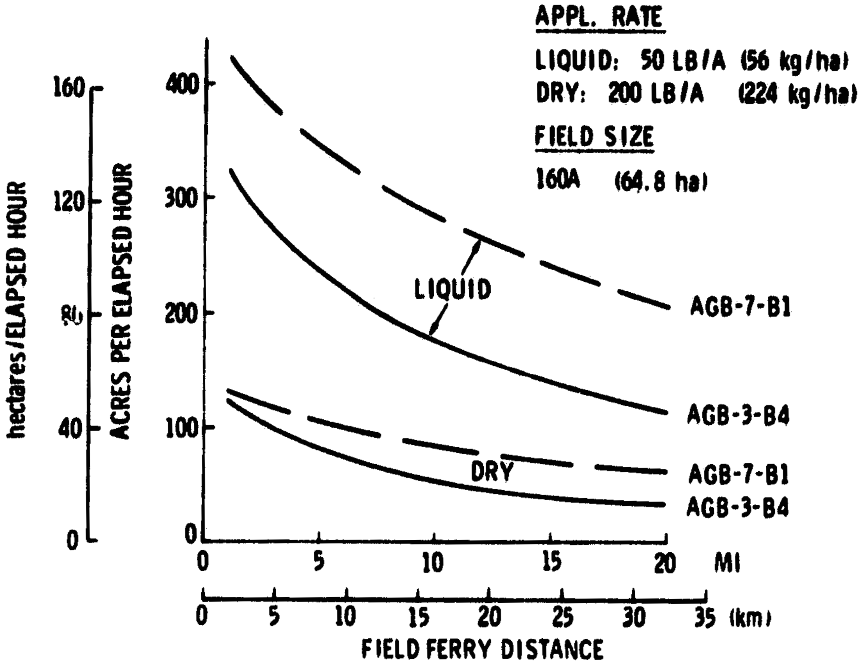

Figure 139. Effects of Field Ferry Distance on Mission Productivity

FIELD FERRY DISTANCE

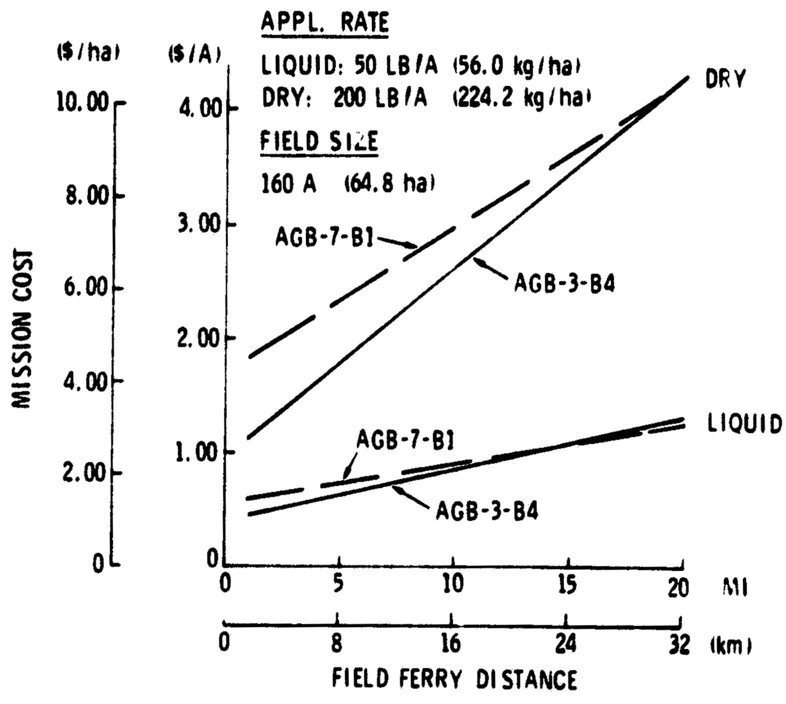

Figure 140. Effects of Field Ferry Distance on Mission Cost

7.3 COST SENSITIVITY DATA

A number of different sets of sensitivity data were run for the refined baseline configuration, to indicate relationships among various cost factors. These are presented below.

Annual Utilization - Figure 141 shows the effects of varying aircraft utilization on aircraft operating cost. The reference case used in all of the cost studies is 600 flight hours per year. The factor enters into operating cost calculation in that certain fixed annual costs are prorated to a flight-hour base using the estimated annual flight hours. Cost elements prorated in this manner are annualized investment, annual inspection, hull insurance, liability insurance, and taxes. Increased utilization will reduce the prorated hourly costs, whereas reduced utilization will increase the prorated hourly costs. The effects of utilization are quite significant, as shown in the figure.

Mission Cost Sensitivity - The sensitivity of mission cost, expressed as cost per acre, to the varous cost elements is shown in Figure 142. It is seen from the figure that aircraft operating cost is by far the major element, and changes in aircraft operating cost will have the most significant effect on overall mission cost.

Aircraft Operating Cost Sensitivity - The sensitivity of aircraft operating cost to its various sub-elements is shown in Figure 143. Annualized investment, representing the cost of purchasing the aircraft, is the major cost element.

Effect of Acquisition Cost - Figure 144 shows how changes in aircraft acquisition cost will affect aircraft operating cost. Both annualized investment and hull insurance are directly dependent on aircraft acquisition cost.

Acquisition Cost Sensitivity - Figure 145 shows the sensitivity of aircraft acquisition cost to its various subelements. The cost of engines is by far the dominant factor. Both aircraft configurations incorporate turboprop

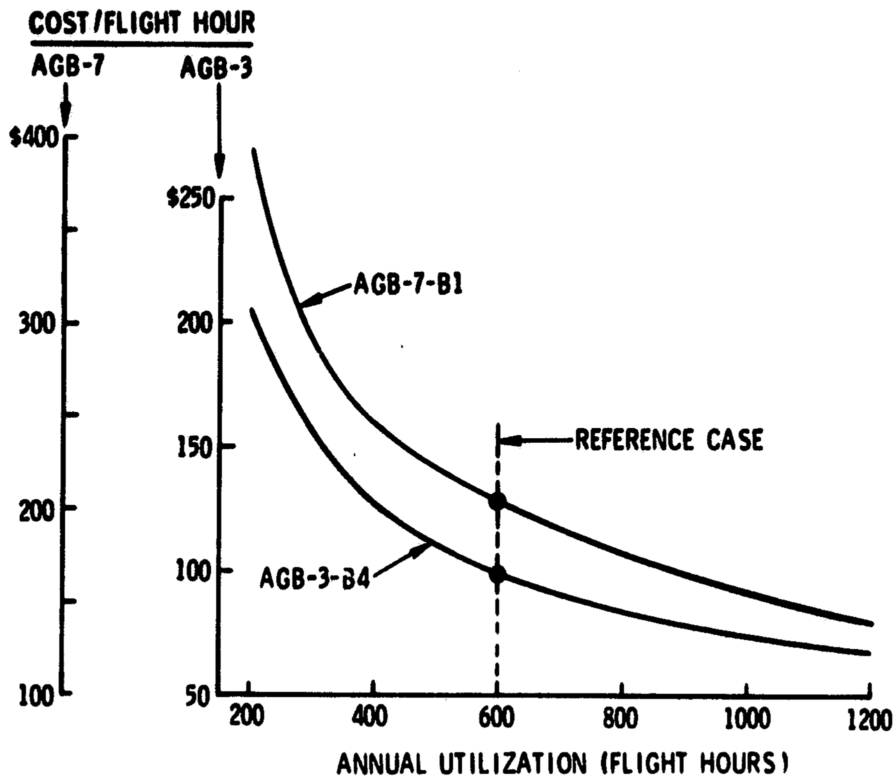

Figure 141. Effect of Utilization on Operating Cost

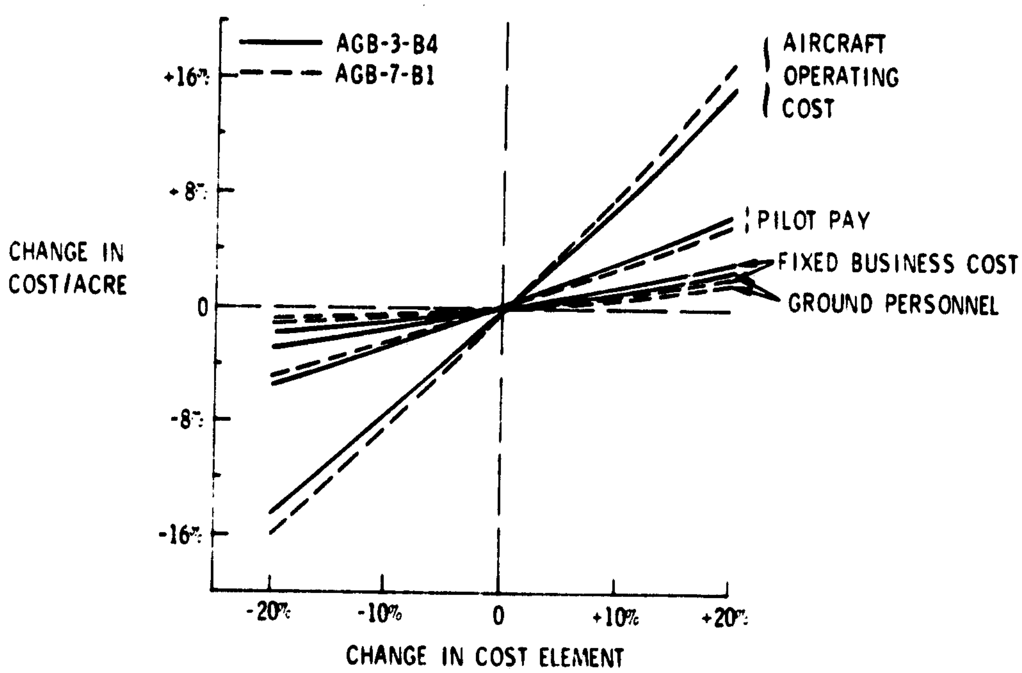

Figure 142. Mission Cost Sensitivity Data

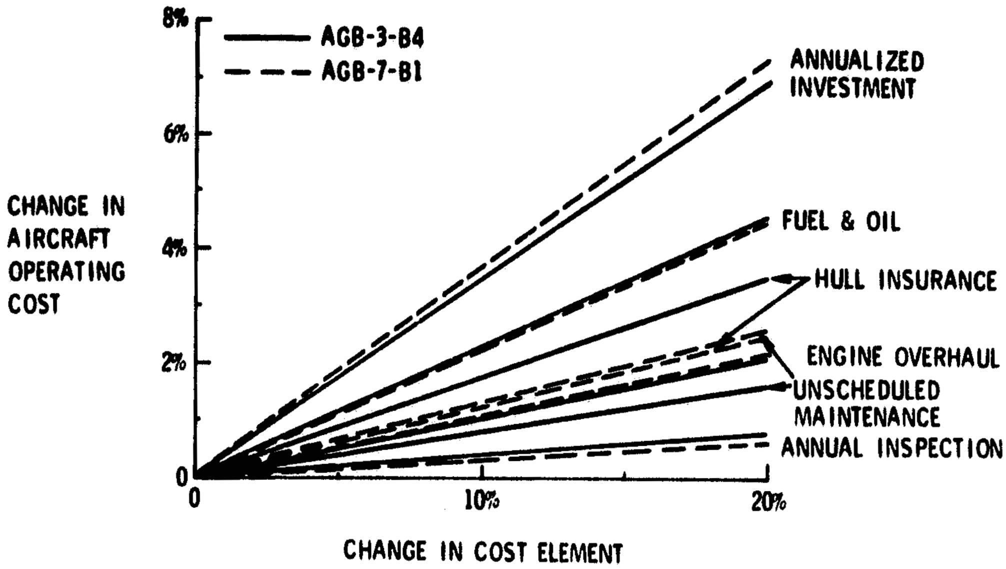

Figure 143. Operating Cost Sensitivity Data

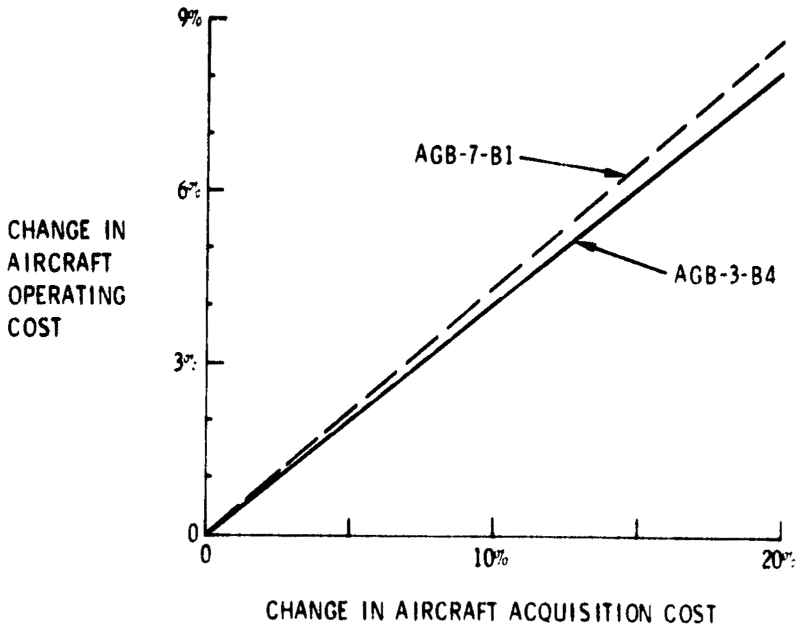

Figure 144. Effects of Acquisition Cost on Operating Cost

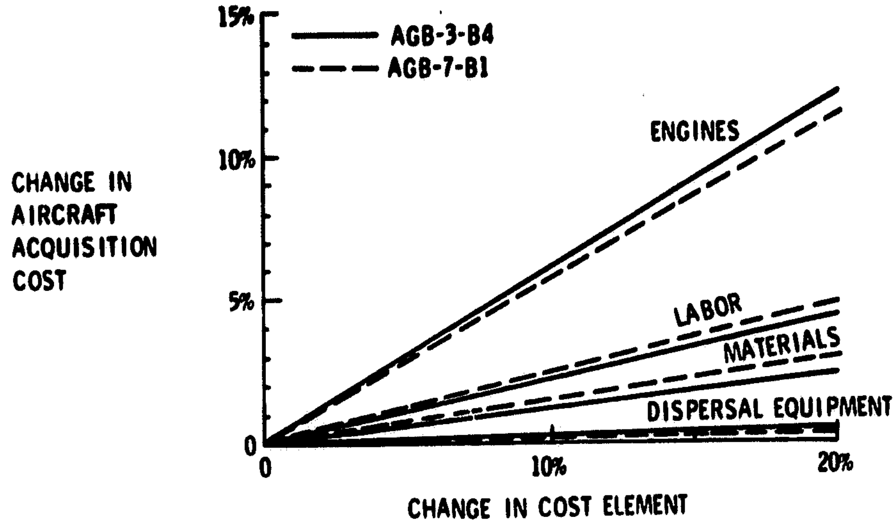

Figure 145. Acquisition Cost Sensitivity Data

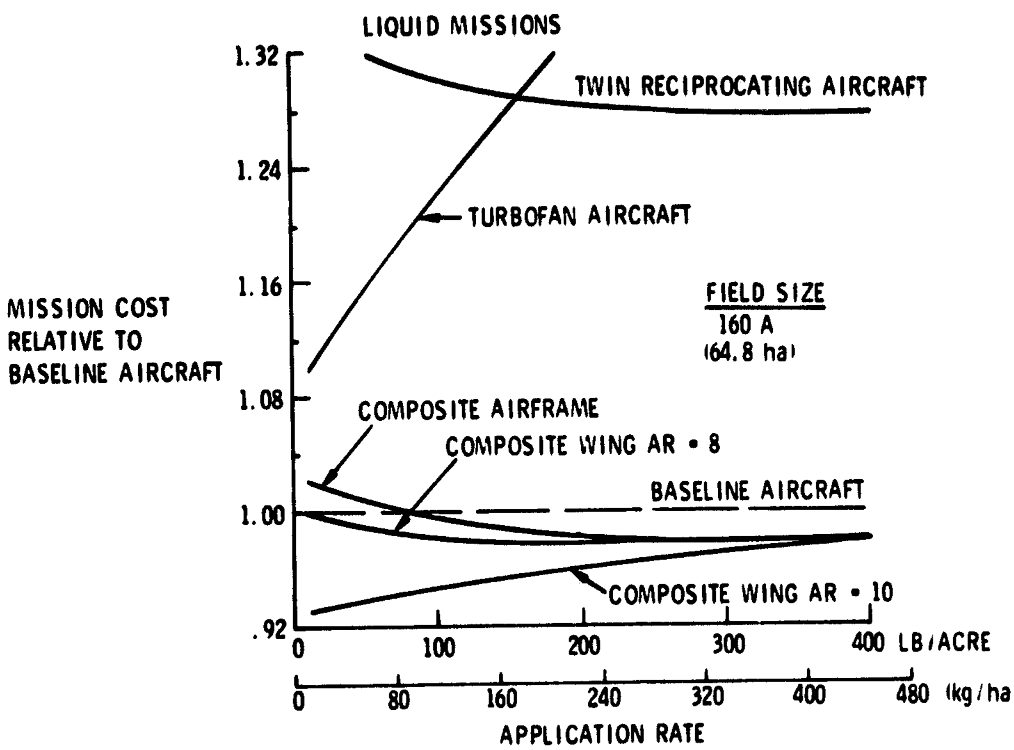

Figure 146. Small Aircraft Configurations with Interest Cost

engines, and the effect of engine cost would not be so dramatic with aircraft utilizing less costly reciprocating engines.

Interest Costs - The method used in this study to calculate annualized investment does not include any representation of interest costs that might accrue in financing the purchase of the aircraft. If interest cost is incurred, this would increase the cost of ownership beyond the levels used in this study, and the increased cost would have the effect of favoring less expensive aircraft in economic comparisons with more costly aircraft. This could conceivably change the selection of the preferred configuration among several contending aircraft concepts.

To examine this effect, one set of comparison data was developed to include interest charges for all of the small aircraft configurations considered in the study. The assumed case is one in which 75% of the aircraft purchase price is financed at 10% interest for seven years with seven equal annual payments. The total accrued interest cost was then spread equally over ten years to be consistent with the treatment of annualized investment, so that 10% of the total was added to the aircraft hourly operating cost based on 600 flight hours per year utilization. By this procedure, hourly operating cost increased by 11% for the AGB-3-B4 configuration and by 12% for the AGB-7-B1 configuration due solely to the interest cost.

Mission cost comparison for all of the small aircraft configurations with interest costs included are shown in Figure 146. The interest costs do not have any appreciable effect on the relative economic merits of these aircraft, since there are only minor changes in the relative standing of the aircraft.

7.4 CURRENT AND FUTURE MISSIONS

As part of the present study, Dr. Ronald W. McClendon of the Department of Agricultural and Biological Engineering of Mississippi State University has compiled extensive data on agricultural missions currently performed by aircraft and missions potentially suited for aircraft in the future. The data were developed from numerous published sources and through personal contacts. Dr. McClendon's report is presented in full in Appendix A.

7.4.1 Current Missions

Table XXV provides a summary of the predominant missions currently performed with fixed-wing aircraft. While there is a great variety of different types of applications and application rates represented in current missions, the great majority of present work consists of low-volume liquid applications generally in the range of one to five gallons per acre (9 - 47 l/ha). A significant grouping of missions also occurs in the range of 100 to 200 lb/acre (112 - 224 kg/ha) representing seeding and fertilizer missions primarily for rice crops. Rice production in the United States is heavily dependent on aerial application because of the high cost of ground equipment suitable to work this crop.

7.4.2 Future Missions

Expanded future missions for agricultural aircraft cannot be projected with any accuracy within the scope of the present study. Areas which appear to offer potential for increased aerial work are discussed below.

No-Tillage and Double Cropping - Trends toward increased usage of these farming methods are readily apparent. No-tillage farming has been made possible by the use of modern chemicals to control weeds rather than using tractors to cultivate the soil. Double cropping is a system of planting two or more crops on the same land in a single year, sometimes with the new crop seeded before the existing crop is harvested. Both methods should increase the use of aerial methods for seeding and weed control.

Forest Management - Aerial application of pesticides and seeding are already an important part of forest management, and these missions will likely increase as additional forest land is brought under scientific management procedures. There are signs that forest fertilizing may also become increasingly important as an aerial mission. These missions are of special interest because of their wide-area nature involving extremely

TABLE XXV - AERIAL APPLICATION MISSIONS

MISSION	TYPE TREATMENT	APPLICATION RATE	
ROW CROPS		PER ACRE	(PER HECTARE)
COTTON	INSECTICIDES	1 - 5 GAL	(9-47 l)
	HERBICIDES	3 - 5 GAL	(28-47 l)
	DEFOLIANTS	3 - 5 GAL	(28-47 l)
SOYBEANS	INSECTICIDES	1 - 5 GAL	(9-47 l)
	HERBICIDES	3 - 5 GAL	(28-47 l)
PEANUTS	INSECTICIDES	1 - 5 GAL	(9-47 l)
	FUNGICIDE	3 - 5 GAL	(28-47 l)
VEGETABLES	INSECTICIDES	1 - 5 GAL	(9-47 l)
	HERBICIDES	3 - 5 GAL	(28-47 l)
	FUNGICIDES	3 - 5 GAL	(28-47 l)
GRAINS			
RICE	SEEDING	80 - 100 LB.	(90-112 kg)
	INSECTICIDES	1 - 5 GAL	(9-47 l)
	HERBICIDES	2 - 10 GAL	(19-94 l)
	FERTILIZER	100 - 300 LB.	(112-336 kg)
WHEAT, RYE, OTHER	HERBICIDES	1 - 5 GAL	(9-47 l)
RANGE & PASTURE LAND	HERBICIDES	1 - 5 GAL	(9-47 l)
	FERTILIZER	100 - 300 LB.	(112-336 kg)
WIDE-AREA PEST CONTROL	FIRE ANT	1 LB.	(.45 kg)
	MOSQUITOES, OTHER	1 QT. OR LESS	(2 l)

large tracts of land, and a larger aircraft may be cost effective in these missions because of greater payload and range capability. Wide-area missions need further analysis to determine the type of aircraft best suited for this work.

Wide-Area Pest Control - Prime examples of wide-area pest control in the United States are the fire ant program and the mosquito spraying mission performed on military reservations by the U.S. Air Force Spray Branch. Other wide-area pest control missions have been performed but thus far on a rather limited scale in the U.S. In other parts of the world, various types of wide-area spraying are performed for control of harmful insects, such as the locust and tsetse programs in Africa involving cooperative efforts among several nations. These types of missions may increase in the future, and larger aircraft may be more effective than the size aircraft used in crop work.

Increased Fertilizer Work - Extensive use of chemical fertilizers is a major factor in the advancement of modern agriculture, and the volume of fertilizer application will continue to increase in the U.S. and world-wide. To date, however, aircraft have performed only a minor role in fertilizer application. With the exception of the rice crop, aerial application with present systems is generally not cost-competitive with ground methods for fertilizer work. There are many cases, however, where the ability to apply fertilizer at the optimum time in the crop cycle without damage from ground machinery would increase crop yield. The use of aerial methods could be greatly expanded if more economical systems can be developed for dry material dispersal.

Fertilizer work is believed to be the single largest potential market for future growth of the aerial application industry. Creation of efficient aerial delivery systems for fertilizer could result in reduced energy requirements for agriculture while improving crop yield.

7.5 COMPARISON WITH GROUND METHODS

Dr. McClendon's report in Appendix A contains data on the comparison of current aerial and ground methods of application. Detailed cost comparisons are difficult, but in current practice aerial methods are generally cost competitive for low volume liquids and for rice seeding and fertilizing. Aerial methods are much faster in all cases, hence the selection of aerial application by the farmer is often dictated by circumstances in which urgency of treatment has greater economic importance than the direct cost of the service. Weather conditions also play an important role in the selection of aerial methods, such as cases where wet soil precludes the use of ground machinery.

Three specific cases were examined to develop a comparison of aerial versus ground methods. Field size, field shape, weather conditions, soil conditions, available equipment, and the type of material being applied are a few of the many variables that must be considered in the selection of methods, and these examples will indicate the role of some of these variables. Costs given in the examples are for application only, based on common practice in the state of Mississippi, and do not include the cost of material.

Fertilization of Wheat - Wheat may require one or two applications of fetilizer: top dressing and/or preplant. If the wheat is planted following a crop of soybeans or the soil contains at least two percent organic matter, then a preplant fertilization is not required. The top dressing should be applied in late February or early March. If the preplant application is needed, then 25 to 30 pounds of nitrogen per acre (28 to 34 kg/ha) are required. For this amount of nitrogen, 75 to 90 pounds per acre (84 to 101 kg/ha) of 33% ammonium nitrate would be necessary. Since this application is done in the fall, consideration must be given to weather conditions and the timeliness of application, since the crop has not been planted. The top dressing requires 80 to 100 pounds trogen per acre (90 to 112 kg/ha) and would take 240 to 300 pounds onium nitrate (269 to 336 kg/ha). This is done about the time the seed heads are beginning to form, and shortly thereafter stem elongation will begin. Damage to the plant after stem elongation begins will reduce yields, therefore crop damage must be considered.

Application by ground is usually done with a spin spreader towed by a tractor. The cost per acre of the spin spreader operation is $1.40 for the spreader, $.90 for the tractor (115-150 hp) and $.26 for labor. This is a total cost of $2.56 per acre ($6.33/ha) for this ground method. The performance rate of the spin spreader is 0.1 hour per acre (.25 hr/ha). These figures are based on the life expectance of the equipment and the average annual usage, all of which could vary.

Application by air is charged at the rate of $2.50 per hundred pounds (55¢/kg) of fertilizer. For the top dressing, applying 250 pounds of ammonium nitrate per acre (280 kg/ha), the cost would be $6.25 per acre ($15.44/ha).

The cost of fertilization is much lower for the ground application, but due to the other consideration such as timeliness, aerial application is widely used.

Fungicide on Soybeans - Fungicides are normally applied at planting time by using equipment attached to the planter. Since this is a combined operation, the actual cost of applying the fungicide would be difficult to determine. When fungicides are applied by air, the cost would be in the range of $2.50 to $3.50 per acre ($6.18 to $8.65 per hectare) because of the large amount of water required. Application of many pesticides is done with a low volume of water, but in the case of fungicides, it is considered ineffective if applied with any less than five gallons per acre (47 l/ha). Tests indicate that even larger amounts are desirable.

Insecticide on Cotton - The application of insecticides may range from one to fifteen applications per year. Entomologists are commonly hired to check for insects and advise the farmer on whether or not to apply insecticides. Usually a regular program is started when insects are found and applications are made weekly throughout the remainder of the growing season. Thus, if weekly applications are used, timeliness would be a major consideration in determining the method of application. Late season applications by ground can also result in damage to the crop.

Currently, the primary method used is aerial application which costs $1.00 per acre ($2.47/ha) for most insecticides and up to $1.65 ($4.08/ha) for some special insecticides. Application by ground is done with a high clearance sprayer or tractor-mounted sprayer. The cost per acre with the high clearance sprayer is $1.26 ($3.11/ha) with a performance rate of .08 hour per acre (.20 hr/ha). The cost of the tractor-mounted sprayer is $1.35 per acre ($3.34/ha). The performance rate is .18 hour per acre (.4[illegible] hr/ha).

Cost comparisons show very little difference between some methods, but consideration of timeliness, weather conditions, and available labor are necessary when deciding which method is preferred.

7.6 COMPARISON WITH CURRENT AIRCRAFT

It is not possible within the present study to provide a valid comparison of the study aircraft configurations with present-day agricultural aircraft in terms of mission cost. Greatly detailed analyses would be needed to develop rigorous groundrules for such a comparison, including conditions of operation, mission definition, and cost accounting procedures. Also, it would be necessary to determine the exact performance characteristics of the aircraft to be considered.

A gross comparison has been developed by use of the operations analysis model. Two present-day aircraft were run in the model over the same set of missions used for the refined baseline configurations. The two current aircraft represented in the model are a "small" aircraft with payload of approximately 1000 pounds (454 kg) and a radial-engine "large" aircraft with payload of approximately 2300 pounds (1043 kg). Cost and performance data used for these aircraft are approximate engineering estimates and have not been verified, hence the analysis results cannot be accepted with any degree of confidence.

The comparison results are shown in Figures 147 and 148, with the two current aircraft plotted relative to the small baseline aircraft, AGB-3-B4. It is seen from these figures that the current "small" aircraft shows an economic advantage at very low application rates with small fields but is otherwise not cost competitive. This result is consistent with the data developed for the initial candidate configurations in the present study, where the 1000-pound (454 kg) payload aircraft was shown to have this type of mission cost pattern relative to larger aircraft.

The data indicate that the AGB-3 configuration is economically superior to the current radial-engine aircraft over the entire range of missions considered. This advantage is relatively small with low application rates in small fields, particularly in liquid missions. Otherwise, the baseline study aircraft is indicated as being 10 to 30% more economical than the radial-engine aircraft.

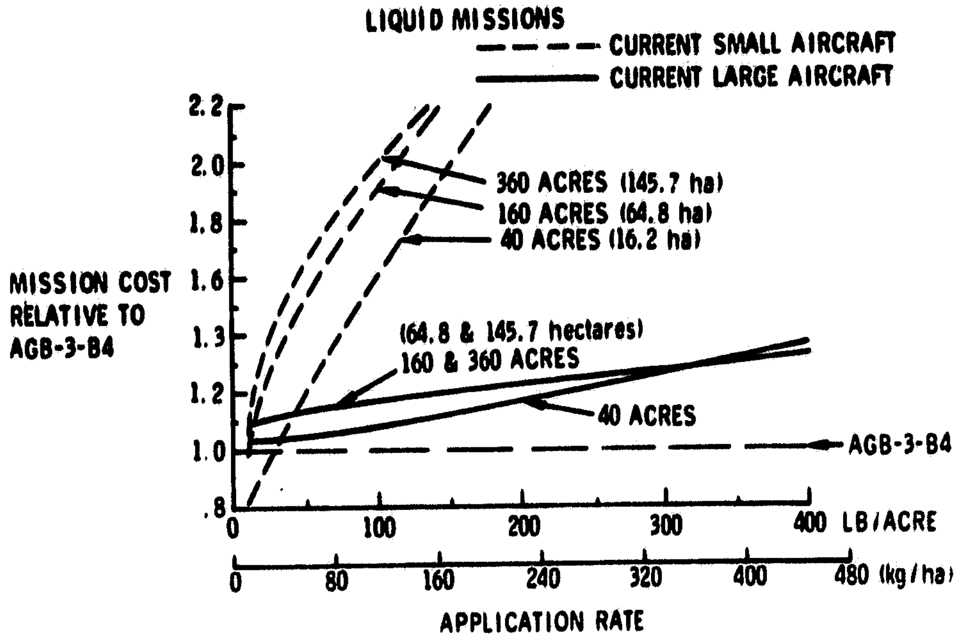

Figure 147. Comparison of Current Aircraft with AGB-3

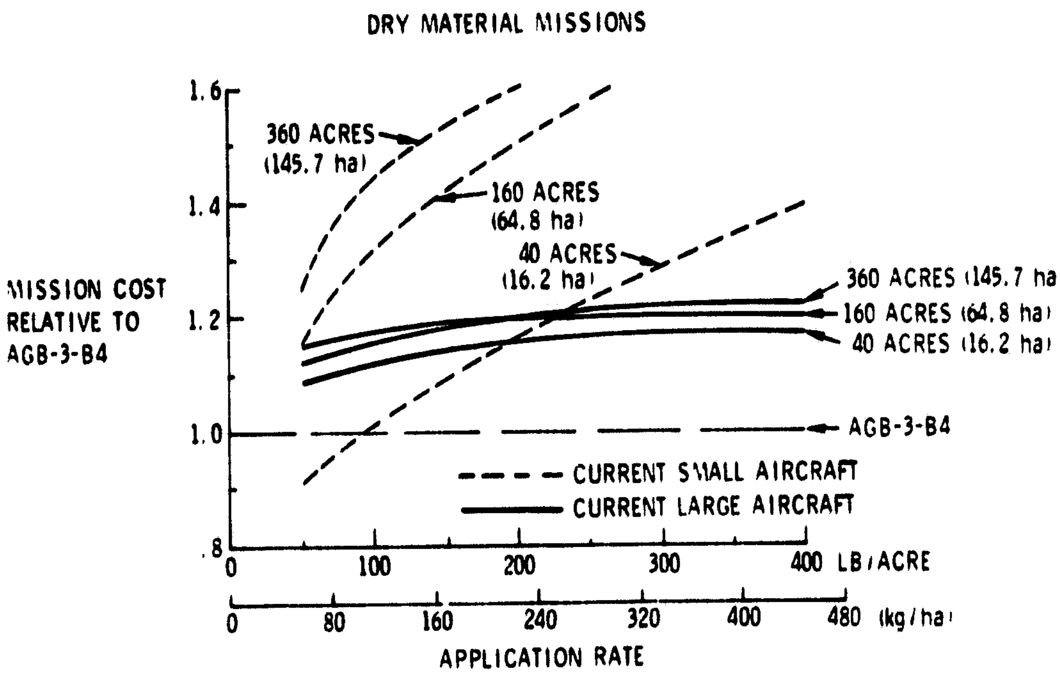

Figure 148. Comparison of Current Aircraft with AGB-3

8.0 SAFETY, OPERATIONAL, AND REGULATORY

8.1 SAFETY CONSIDERATIONS

System configurations developed in this study incorporate established safety features for agricultural aircraft. Basic guidelines for aircraft design include good pilot visibility; crash-resistant and energy-absorbing structure; placement of fuel tanks remote from the cockpit; and sealed cockpits to provide pilot protection from chemicals. Cockpit pressurization/air conditoning is recommended both for pilot comfort to reduce fatigue and to prevent chemicals from entering the cockpit. As noted elsewhere in this report, additional research is needed to examine pilot workload and fatigue factors particularly with respect to handling qualities criteria.

8.2 FLIGHTPATH GUIDANCE SYSTEMS

8.2.1 General

Electronic guidance systems offer potential for aircraft positioning and swath guidance in aerial application missions. Possible advantages of such systems, if determined to be effective, are improved precision and uniformity in the swath pattern and elimination of flagmen and/or mechanical markers on the ground. Discussions with the Advisory Committee and other industry contacts indicate that an electronic guidance capability is strongly desired by aerial application operators.

The specific capability needed from the guidance system is accurate swath positioning and tracking. This includes the ability to fly successive swaths closely parallel to each other and with correct lateral offset to avoid excessive overlap or gaps between swaths. The ability to locate the particular field to be treated is also a desirable capability of the guidance system, but this is secondary to the swath guidance function and should not be allowed to introduce added complexities to the system.

In the present study an effort has been made to provide an initial engineering overview of the guidance system subject. This includes an assessment of accuracy considerations, a survey of guidance techniques and existing candidate systems, and a review of possible display techniques for presenting guidance data to the pilot.

8.2.2 Accuracy Considerations

The positioning and guidance requirements for aircraft used in aerial application operations fall into two general categories: for large area applications, over thousands of acres at altitudes of 100 feet (30 m) and up, accuracies within ±10 feet (±3 m) are probably adequate; for small and medium field applications at altitudes of 25 feet (8 m) and less, much greater accuracy is required. The accuracy requirements for low-level field work can be further divided in two groups: high accuracy and low accuracy. In today's operations high-accuracy work is characterized by use of flagmen or special markers on the ground to mark the beginning and end of each application swath.

Seeding of rice is a good example of a high accuracy application task. There are two reasons for high accuracy. First, mistakes are costly since overlaps are wasteful of seed and voids are wasteful of land. Second, mistakes are obvious since the overlaps and the voids become clearly visible as soon as the seeds begin to sprout. Similarly, some fertilizing operations also tend to exhibit the faults or skills of the pilot. Therefore, flagmen are nearly always used for these applications. One typical southeastern operator estimates that 30-35% of his work falls in this category.

Applying insecticides to cotton fields on the other hand falls into the category of low accuracy tasks. It actually does not matter if some ground is missed, since the damaging insects move about sufficiently to come in contact with the controlling chemicals. Most of this kind of work can be done without the aid of flagmen. Electronic guidance for such application would not show a direct economic justification, but the operator who uses an electronic system will probably have a sales advantage if such systems come into general use. Ultimately some environmental and economic benefits may also be realized. In any event, these applications do not contribute to the establishment of optimum accuracy requirements for the guidance system.

It appears to be the consensus among operators contacted that the use of flagmen for the high accuracy application tasks yields adequate results. No improvement is needed in terms of accuracy although a more dependable and less costly method is highly desirable. It is difficult to obtain factual data on the numerical value of the accuracy obtained with the use of flagmen but it appears to be on the order of 2 to 3 feet (.6 to .9 m). It may therefore be concluded from a practical standpoint that accuracy greater than ±2 feet (±.6 m) is not required and ±3 feet (±.9 m) is probably the optimum.

A further limit on providing increased accuracy is derived from the pilot's tolerance to control indications from a guidance instrument. If too much concentration is demanded from the pilot, the system will be counterproductive. Specific data on that subject are scarce, but a similar situation may be helpful of comparison. It is easy and comfortable to guide an automobile, six feet wide, in a freeway traffic lane twelve feet wide, but a traffic lane ten feet wide becomes fatiguing. This example provides some subjective insight into the difference between ±3 feet and ±2 feet guidance at highway speeds when the steering signals for the automobile driver come from the best possible "head-up-display" arrangement, the roadway itself.

It can be seen from the discussion that much additional work is needed to establish specific accuracy requirements for electronic systems for swath guidance. This should include determination of actual accuracies needed in the swath pattern itself for various types of missions; practical limits for pilot response to guidance inputs; and also limits for aircraft response to pilot control actions based on guidance data. Flight tests and/or simulations may be necessary to determine the guidance system/pilot/aircraft interactions.

8.2.3 Review of Guidance Techniques

This section provides an overview of various electronic guidance techniques that might have potential application to the aerial dispersal mission. The techniques are considered in three categories: self-contained systems requiring no ground devices; local area systems; and wide area systems.

8.2.3.1 Self-contained Systems - The ideal positioning system would be self-contained and require no special external references. Ideally, it should not be necessary to emplace flags, balloons, transponders, or reflectors in order to operate the system. A pilot who knows where he is going and where he has been may be regarded as the simplest possible self-contained guidance system. It is also the most economical system and therefore the most widely used. For many applications it is a perfectly adequate system.

Other self-contained systems include inertial guidance, map-matching, radiometric correlation, radar, and video tracking. Inertial guidance systems are designed for long-range navigation and their accuracies are stated in nautical miles per flight hour. A reasonably good inertial guidance system maintains positional accuracy within one-half nautical mile per hour. However, this level of accuracy is not normally adequate for the aerial application tasks since the velocity errors approach one foot (.3 m) per second of flight. An inertial system potentially suitable for some aerial application missions is discussed in the following section on candidate systems.

Map-matching techniques, such as are employed for cruise missile guidance, might be used for some of the aerial applications tasks. The salient limitation would be that this method cannot be used over water or over extremely flat terrain. Radiometric correlation would suffer a similar limitation in that the radiated energy from a uniformly illuminated surface would not yield the required reference points. Inexpensive radar equipment is becoming available as a result of automotive interest in this technology, and it appears feasible that radar positioning systems might become available for agricultural aircraft in the future. No suitable system of this type is known to be available at present.

Video ranging and tracking offers good technical feasibility. The military now have systems which are capable of keeping an airborne video camera aimed at a specific target with deviations of just a few minutes of arc irrespective of platform movement. For applications where the entire operation is performed within line-of-sight of some recognizable objects or terrain features, a system based on this capability would be both technically and economically feasible. As far as can be determined, no suitable system of this type is currently under development, although all the necessary hardware is available off-the-shelf.

8.2.3.2 Local Area Systems - This category is comprised of those techniques which require the placement of artificial reference points, either active or passive, as part of the operating system. The simplest and most widely applied method in this category makes use of flagmen or markers on the ground to mark the beginning and end of each swath.

There are several electronic systems available that use transponders placed on the ground in the operating area. The workable range seems to be approximately 20 to 50 miles (32 to 80 km). Assuming that these systems provide acceptable performance at acceptable cost, the only real drawback is the necessity to set out the remote units. Some operators solve this problem by locating one unit at their home base and putting the other unit on a pickup truck which is moved to the most favorable position for each particular operation. This eliminates flagmen but necessitates a truck-driver.

A more desirable approach to the mechanization of the local area system would make use of some passive devices on the ground. As far as can be ascertained, there are no such systems on the market at the present time. For instance, inexpensive radar corner reflectors, or laser reflecting spots, could be emplaced permanently in fields that are repeatedly treated. The simplest approach would be to place such a device at the end of each row or swath, and simply have the onboard unit aimed forward with a provision to offset for crabangle. A next level of sophistication would make use of just a few of these ground reference markers and provide a capability to compute position on board from parameters such as range, range-rate, and/or angles to the reference. Using the capabilities of existing laser technology it would be possible to use those three parameters against a single target and achieve the necessary accuracy. The salient fact to bear in mind when considering these operational possibilities is that the absolute position is not important for the agricultural mission but rather the relative position with respect to some boundary line that is usually quite obvious.

Within the category of local area systems there is a third group of systems that might be considered in addition to those that might be termed either active or passive. That is the group of emitters that are active but not cooperative, as are the transponders. Most of the wide areas systems fall into this group. In general, the non-cooperative systems produce hyperbolic lines of position while the cooperative transponder-type systems produce circular lines of position. The on-board equipment tends to be more complex and bulky with the hyperbolic approach, but with the advent of the microprocessor the differences may become less significant.

8.2.3.3 Wide Area Navigation Systems - This category would include the various commercial and military navigation systems that are already in use or which are planned for use within the near future. These systems have not been evaluated for their short term capabilities in the present study. For instance, Loran-C might well be sufficiently accurate to maintain a specified separation between two successive swaths that are separated in time by less than a minute. There is also the potential for a combination of existing wide area systems with some on-board equipment such as radar or doppler and the necessary computation capability to provide for the unique short-term navigation accuracies that are desirable for the ag aircraft.

8.2.4 Existing Candidate Systems

A brief survey has been made of guidance equipment manufacturers to identify existing systems that might be suitable for the aerial application mission. These results are presented below.

Litton LTN-72/76 - In discussions with the manufacturers and personnel of the U.S. Air Force Spray Branch, it was determined that this self-contained inertial system can be referenced to local ground features to overcome the lack of short-term accuracy normally inherent in inertial systems. By circling a local landmark several times and pressing a "pickle switch" each time the reference point is at nadir, as determined by a viewfinder with cross-hairs, the system is effectively "anchored" to that reference for local operation. The manufacturer states that in helicopter operations over large forest areas, operating costs can be cut by a factor of five when using the inertial equipment in lieu of ground beacons, and that acceptable accuracy has been maintained in trials that established these results. The system costs approximately $150,000, but it may be leased for a period of time to determine its effectiveness in a particular operation. In wide-area missions, the system could be utilized in a single aircraft flying lead for several aircraft in formation.

Del Norte Flying Flagman - This system consists of an airborne unit which operates against ground transponders for reference. It utilizes the 8.9 GHz region of the RF spectrum and employs 2, 3, and 4 transponders placed up to 50 miles (80 km) from the operating area. At that range the aircraft remains within ±10 feet (3 m) of the desired position but, according to a company spokesman, "if ground references are available in the operating area, such as a fence line, successive passes can be made at specified ofsets from this ground reference within ±3 feet." This, it appears, falls within the assessment for the desired accuracy made in a previous paragraph, and the system is said to be used successfully in lieu of flagmen for seeding rice and other high accuracy application tasks. A left/right steering indicator with selectable sensitivity is employed in the cockpit to guide the pilot. The equipment weighs approximately 40 pounds (18 kg) installed in the aircraft.

Montorola Mini-Ranger - This is also an airborne system which uses transponders on the ground for positional reference. It operates at C-Band (5400-5600 MHz). In its basic configuration it employs two transponders at up to 20 miles (32 km) from the operating area. Company spokesmen report that on a swath-by-swath basis "repeatability" is better than the ± 3 feet (.9 m) objective in rice seeding work. A left/right steering indicator is used in the cockpit. This instrument also features a distance meter which counts down to the restart point where the last mission left off. Installed in the aircraft the equipment weighs approximately 33 pounds (15 kg).

Teledyne Hastings-Raydist - Unlike the Del Norte and the Motorola systems, the Raydist is a non-line-of-sight continuous wave, phase comparison system. At least two basic configurations are available, the DRS-H, and the "T." Both are said to have a "sensitivity of approximately one-half meter and a positional accuracy of approximately three meters or better in areas of good geometry." It appears that this would meet the short-term requirements of the agricultural aircraft guidance task. The DRS-H sytem uses two ground stations and the "T" system uses four. The ground stations are battery powered and may be located as far away as 150 miles (241 km) in daytime operations and 250 miles (402 km) at night. Two different antenna towers are used depending on the desired range: 50 feet (15 m) and 102 feet (31 m). For airborne operations there is a pilot's control console and a left/right and up/down display instrument. The airborne equipment weighs 32 pounds (15 kg) plus the weight of installation.

Decca Survey - Decca Survey Systems markets the Del Norte system noted previously. Decca earlier manufactured a system called Agrifix which is still used in some parts of the world. It is a hyperbolic system, with a channel "auto locking" feature that prevents lane skips and overlaps. It operates in the 1.7 - 1.8 KHz region and provides 85 foot (26 m) lanes which can be resolved into one hundredth of a lane width. The system appears to be suitable for aerial application operations, but a manufacturer's representative reports that there are no plans to revive production at present.

Cubic CR-100 - The Cubic Corporation manufactures high precision guidance and positioning equipment, and the Cubic CR-100 would probably come close to meeting the assessed requirements. However, the system is not intended nor packaged for typical aerial application operations. This equipment is used extensively for test and checkout of other systems at Air Force and other test ranges.

Approximate acquisition costs were obtained for three of the systems using ground beacons. These costs range from about $28,000 to $67,000 per system. About two-thirds of the cost is for the airborne portion of the system and would be incurred for each aircraft in which the equipment is installed. The remainder of the cost is for the ground transponders.

8.2.5 Accuracy Assessment

From the review of various systems in use or under development, it is not certain that any system meets the accuracy required to obviate the use of a flagman for all applications. Some advertised accuracies reach 10 feet (3 m); some orally stated accuracies are ±3 feet (.9 m) or less. Even if it was certain that ±3 feet (.9 m) can be obtained, there are numerous conditions that must be examined before the stated accuracy could be declared adequate with any confidence. Further detailed analysis would be required to state categorically that the required accuracy can be obtained within the state-of-the-art and at an affordable price.

The basic problem in position location is the determination of the coordinates of a remote point with respect to some given reference or references. In the case of this study, that remote point is the aircraft, and the fixed or known reference may be a flagman, a visible boundary line, some prominent natural or man-made feature, or an electronic emitter. Since no measurement can be made without some error, the actual position of the aircraft is surrounded by an area of uncertainty within which is found the desired position. For our stipulated requirement, this area is assumed to be a circle with a radius of three feet (.9 m). Whether that should be taken to be the Circle of Equal Probability (CEP), or some higher probability circle is not certain at this point. The CEP is that circle which contains both the actual and the desired positons 50% of the time. In fact, a circle is probably not the optimum shape of a figure containing the allowable errors for the agricultural aircraft positioning problem.

The agricultural aircraft on a low level pass over a field poses its own peculiar location geometry. Only the cross-track errors are really significant. The along-track errors are usually of little or no interest since the overflight of some recognizable boundary line indicates the start and stop of the operation for each swath. In such a case, the allowable errors are contained not within a circle but within an ellipse with considerable eccentricity. In general, the simple circular approach favors the vendor of the equipment in statements of accuracy, whereas complex analysis of overlapping ellipses is necessary to determine the actual capability of the equipment.

In conclusion, it is not possible with existing information to determine whether any given electronic guidance system is capable of meeting the needs of the aerial application mission. Because of many complexities associated with such a determination by analytic means, actual testing in real or simulated application missions is recommended as the most practical method of determining system suitability.

8.2.6 Cockpit Displays

The method of displaying data to the pilot is of crucial importance to the problem of guidance and positioning of agricultural aircraft. In low-level application work the outside environment demands the full-time attention of the pilot. A brief assessment has been made of possible display concepts that might be suited to this mission application.

8.2.6.1 Head-up Displays - Steering information may be presented by either visual or aural means. In the visual category one may distinguish between conventional and head-up displays (HUD). Displays that make use of the pilot's peripheral vision without necessity to refocus may be regarded as the simplest possible HUDs. A simple set of lights denoting left/on-course/right may be placed where they are within the pilot's peripheral vision. The interference of sunlight at various angles is the main problem with any display of lights.

Another peripheral vision device which would not suffer from poor visibility in high ambient light is the "barberpole" display. This consists of a rotating cylinder with spiral stripes. Two horizontal cylinders might be used to indicate left/right and the magnitude of the deviation could be indicated by the rotational speed. One vertical cylinder could possibly be used with the direction of the deviation shown by the direction of rotation. This offers a simple inexpensive solution to the display problem, but optimum placement and mode of indication for the aerial applicator aircraft need to be determined.

Not so simple, and rather expensive, are a host of electronic HUD devices. Two general categories may be distinguished: pilot mounted or aircraft mounted. The pilot mounted devices consist of helmet or goggle mounted projection systems which present a display close to the pilot's eyes but which is focused at infinity. This makes it possible for the pilot to observe his environment and his steering information without refocusing his eyes. They also take in account the pilot's head movements. The steering information can be presented as a lighted "swath" appearing ahead of the aircraft and seemingly fixed with respect to the ground.

The aircraft mounted HUD would present the same information either projected on the inside of the windshield or on a special transparent plate if the standard windshield is not located at the proper angle. For this projection there is no compensation for the pilot's head movements.

In general, the electronic HUD suffer the same disadvantages that the simple steering lights have. The constant shifting of the sun angle would often "wash out" the display. In addition these devices tend to be expensive.

8.2.6.2 Conventional Instruments - The systems which are available off-the-shelf for steering and guidance of agricultural aircraft all make use of conventional instrument-panel moounted left/right steering indicators.

While these are less than ideal, such indicators may well be the best that are available. One person contacted during this study cited 15 years experience as a helicopter test pilot during which time he used and tested every conceivable guidance indicator system. In his opinion, the ag pilot uses the instrument only briefly to line himself up with external reference points, and then he will not look again at the instrument until the beginning of the next swath. Simple left/right indicators may be adequate in that case.

8.2.6.3 Aural Guidance - The term "display" implies visual instrumentation. In the more general sense of providing guidance to the pilot, aural or sound devices should also be considered. Such systems have been in use for many years for various guidance and homing applications such as the "A" and "N" signals from the airways range stations. Numerous advantages can be cited for aural systems. They are inexpensive, especially in comparison with the sophisticated head-up displays. The aural "input channel" to the pilot is not nearly as crowded as the visual channel. There is no need for looking down or visual refocusing. It provides for uninterrupted guidance information. Some drawbacks may also be anticipated. The noise level in many ag aircraft would necessitate the use of earphones. There would be no obvious correlation between the coded sounds and external visual references. The tone code would not be directly understood in terms of left/right steering. It would require practice.

8.2.7 Additional Microprocessor Functions

If electronic guidance systems are incorporated into agricultural aircraft, the opportunity will exist to employ the guidance system microprocessor for other functions. Use of the guidance computer for swath and material ejection computations should be feasible, including possible adjustments to dispersal control settings for varying wind and other environmental and flight conditons. Ultimately, it should be possible to integrate the microprocessor into an automatic dispersal control system. The guidance computer also has potential for other functions such as engine and aircraft performance monitoring, dispersal coverage recording, and others.

Of the existing systems surveyed in the present study, only the Litton system presently has sufficient capacity in the positioning computer for any significant addition of auxiliary programs. Additional capacity could be provided in the other systems, however, if a need for the capability were determined.

8.3 REGULATORY CONSIDERATIONS

An evaluation was made of existing airworthiness and operating requirements for agricultural aircraft as contained in the Federal Aviation Regulations (FAR's) and Civil Aeronautics Manuals (CAM's). The purpose of the evaluation was to determine if any inadequacies exist in current regulations of a nature that could be remedied by research and development activities.

The basic evaluation of airworthiness requirements was performed by Dr. E. J. Cross, Jr. of the Department of Aerophysics and Aerospace Engineering of Mississippi State University. The investigation included a review of the regulatory documents and interviews with operators and manufacturers who have been directly involved in certification of agricultural aircraft. Dr. Cross' findings were then closely reviewed with the Advisory Committee to develop recommendations for research.

The full report of Dr. Cross' evaluation is contained in Appendix B. Based on these data and their own experience, the Advisory Committee concluded that definite inadequacies exist in current regulations for certification of agricultural aircraft.

A fundamental difficulty with current regulations is the lack of clear and specific certification requirements for agricultural aircraft. These aircraft may be certificated under normal category requirements (FAR Part 23), but exceptions to these requirements are allowed. CAM 8 Appendix B, Airworthiness Criteria for Agricultural Aircraft, may be used for guidance but is not mandatory. Consequently, new aircraft and modifications to existing aircraft may be certificated to a combination of requirements taken from

Part 23 and CAM 8, and requirements negotiated with the responsible FAA region.

Inadequacies existing in this situation arise from the following:

- **Part 23 contains requirements that are inappropriate for the agricultural aircraft mission.**

- **CAM 8 is outdated in many areas and does not address modern-design aircraft, such as turbine-powered aircraft. Additionally, CAM 8 requirements are overly vague in some areas, such as in the area of stick force gradient.**

- No specific guidelines are given for exceptions to normal category requirements.

- Many requirements are subject to FAA interpretation, and these interpretations vary among FAA regions.

From review of the circumstances, the Advisory Committee recommends that research be conducted in several specific areas for the purpose of supporting improvements in airworthiness regulations. The specific research areas are as follows:

- Research to establish minimum stability criteria suited to the agricultural aircraft mission;

- Research to examine stall and post-stall behavior in those flight regimes specifically associated with the agricultural aircraft mission;

- Expanded VGH data collection and analysis specifically for agricultural aircraft to provide a factual data base for re-evaluation of airworthiness design criteria, including strutural criteria.

In addition to these research activities, the Advisory Committee recommends that a task group be constituted to draft a separate FAR part specifically for agricultural aircraft. This document would contain all requirements applicable to these aircraft, based on the mission-dedicated nature of the aircraft, and would clarify those primary areas presently subject to negotiation and interpretation. It is recommended that the task group be formed by NASA with representation from aircraft manufacturers, operators, and technical specialists. FAA personnel should participate as observers.

It is also recommended by the Advisory Committee that standard guidelines be established for FAA region use in interpreting the existing airworthiness criteria until such time that more definitive regulations are issued.

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9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

The primary conclusions of the study program are as follows:

- The small baseline study aircraft is cost effective over a very wide mission range. The aircraft is well suited for both liquid and dry material missions ranging from low to high application rates.

- The large baseline study aircraft appears to have limited utility in crop missions. The aircraft has good mission economics for high-volume liquid applications, but there are apparently few missions of this type available. The aircraft would be well suited for liquid fertilizer work. For dry materials, however, the large aircraft is limited by the inefficiency of current dry material spreaders. The aircraft would become more attractive if improved dry material dispersal systems are developed.

- The effect of various design parameters on mission productivity varies significantly with the mission to be performed. Ferry speed and structural weight were found to have major effects on productivity, particularly for high application rate missions. Swath width and turn time increase in importance for low application rate missions.

- Major advancements are needed in dry dispersal systems. The high drag of conventional dry spreaders is a serious determent to aircraft productivity, and aerial methods are not likely to be competitive for a wide range of dry material work without greatly improved dispersal methods.

- Specific handling qualities criteria are needed for agricultural aircraft as a basis for flight control system design. There presently are not adequate data available to determine the best

trade-off between stability and controllability for the dedicated agricultural mission.

- o Some changes are needed to current airworthiness regulations for agricultural aircraft. Present regulations are not definitive with respect to agricultural aircraft in several areas, and the guidelines of CAM 8 do not reflect current design technology. Consequently, some requirements are being applied which are inappropriate to the dedicated agricultural mission, and specific certification criteria are subject to varying interpretations in a number of areas.

- o While not specifically addressed in the study effort, the need is apparent for methods to predict particle/wake dynamics and swath characteristics. There presently are no accepted techniques for determining the effects of aircraft design characteristics on swath characteristics. Expanded technical data are required in this subject area as a basis for developing analytic prediction methods.

9.2 PROMISING CONCEPTS

The results of the study indicate that the following concepts offer promise for improved productivity in future agricultural aircraft. These areas are considered to merit additional investigation.

- o An advanced biplane design of the general type represented in the AGB-7-TB1 configuration. The aircraft offers several potentially attractive features, but it requires more detailed investigation to verify technical and economic characteristics.

- o Low-drag liquid systems. Dispersal system drag has a significant detrimental effect on mission productivity, and design concepts are available for reduced drag. If acceptable operational and maintenance characteristics can be achieved, low-drag designs should be economically attractive.

- Free release of dry material. The limited test data available for this dispersal method suggest the possibility of improved performance and economics over conventional spreaders for high application rates representative of most fertilizer work. Additional testing is needed to establish swath characteristics.

- Multiple hopper designs. Benefits were indicated in the use of dual hoppers in some of the configurations examined in the study. This in effect is a method of placing the material nearer the desired dispersal point, with a reduction in material transport power required during flight, particularly for dry materials.

- Dry material dispersal along the wing. While specific means of transporting material along the wing were not addressed in the study, the separation of dispersal points along the wing span is indicated as providing improvements in swath width. Significant drag reduction from that of conventional spreaders should also be possible if feasible methods can be found for material transport internal to the wing.

- Composite materials for aircraft structure. Composite materials are indicated as being effective for both weight reduction and corrosion reduction. More detailed analysis is needed to determine specific applications, and data are needed on the effects of agricultural chemicals on these materials. Both laboratory and field service tests are warranted to verify near-term feasibility of composite materials applications in selected high-corrosion areas on current aircraft.

9.3 RECOMMENDED RESEARCH

9.3.1 Basis for Recommendations

Recommendations given in the following paragraphs for additional research and analysis are based on findings and conclusions reached in the study program. These include qualitative determinations of a judgmental nature, as well as findings based on the quantitative mission analyses.

A number of the recommended areas would require additional investigation to determine whether sufficient merit exists to pursue the concept in more detail. The study program Advisory Committee provided input in several of these recommendation areas, particularly with respect to airworthiness regulations. No attempt has been made to rank the research areas in order of priority, and no consideration was given to funding requirements.

9.3.2 Additional Aircraft Studies

Additional aircraft studies are recommended to refine promising system concepts identified in the present study and to evaluate additional concepts which could not be addressed in the present study. Areas considered to merit additional study include the following:

- The advanced biplane concept and possibly other aircraft configurations, including an aircraft with canard controls.

- Dispersal system power concepts, including engine power take-off methods and auxiliary power plants.

- Dry material dispersal concepts, with particular emphasis on methods for transporting material internal to the wing for dispersal along the wing span.

- A more detailed composites aircraft configuration study to establish better confidence in indicated weight reduction benefits and identify specific design approaches.

- Mission analyses for wide-area missions to determine the size aircraft best suited for these missions and the relative importance of various design characteristics.

9.3.3 Composite Materials for Corrosion Reduction

Composite materials applications in selected high-corrosion areas appear to offer near-term benefits for present aircraft. Two lines of additional investigation are recommended:

- Laboratory tests to develop data on the effects of agricultural chemicals on the leading composite material candidates for agricultural aircraft structure.

- A field service test in which composite material components are installed on operational aircraft and closely monitored over a period of normal operation. Several activities will be needed to reach the actual test stage, including development of a specific program plan and technical studies to select materials and aircraft applications.

9.3.4 Particle Behavior and Swath Predictions

It is recommended that NASA continue the present research into liquid and dry particle dynamics and interactions with the aircraft flow field. The research should be pursued to the point of providing data and methodology for predicting swath width and pattern as a function of aircraft characterisics for various materials and environmental conditions. This capability is necessary for optimum design trade-offs to maximize aircraft effectiveness in aerial application missions.

9.3.5 Experimentation with Dry Material Devices

A broad range of dry material dispersal devices should be investigated in an effort to improve aircraft productivity in this mission. A number of different concepts has been suggested within the industry at various times, but generally the resources have not been available to verify technical feasibility or performance. Tests of experimental hardware is recommended for device concepts that appear from a theoretical viewpoint to offer performance improvements.

9.3.6 Flight Tests and Simulations for Handling Qualities

Tests and analyses are recommended to develop handling qualities criteria. Such tests must involve pilot performance and opinion for a representative sample of pilots in flight regimes closely matching agricultural missions. Ground simulators may be suitable for this purpose, but actual flight tests are recommended. A variable-stability flight vehicle should be utilized. In conjunction with these tests, an evaluation should be made of the broad question of pilot workload and fatigue factors relating to safety and mission productivity.

While this recommendation is directed specifically to the need for design criteria, the recommended testing also relates to research to support changes in airworthiness requirements as noted in a subsequent paragraph.

9.3.7 Guidance System Evaluation

Flight testing in actual or simulated agricultural missions is recomended to evaluate candidate electronic guidance systems that appear suited for the swath guidance function. These tests would also serve to develop criteria for future guidance systems for the agricultural missions.

9.3.8 Research and Development to Support Regulatory Changes

These recommendations fall into two categories: (1) research specifically related to technical airworthiness criteria; and (2) effort to improve overall format and content of airworthiness regulations for agricultural aircraft.

In the first category, the following specific research areas are recommended:

- Research to establish minimum stability and control criteria for agricultural aircraft. Data required for this purpose would be available from the handling qualities testing previously recommended.

- Research to examine stall and post-stall behavior in those flight regimes specifically associated with the agricultural mission.

- Expanded VGH data collection and analysis as a basis for re-evaluation of existing airworthiness criteria, including structural criteria.

In the second category, it is recommended that a government/industry task group be formed to prepare a draft of a separate FAR part specifically for agricultural aircraft. This document should contain all of the airworthiness requirements applicable to these aircraft.

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APPENDIX A

AGRICULTRUAL AIRCRAFT MISSIONS

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I. Introduction

This report surveys the role aviation plays in agriculture today and the developments that could change its role in the future. Although all crops and states are not included in the report, the selected ones comprise the majority of agricultural aircraft use. All information in this report has been compiled from current literature, publications, and contacts with professional personnel in agricultural related areas.

II. CHEMICALS USED IN AGRICULTURE

Table 1 includes some of the more commonly used chemicals in agricultural practices today. This table shows the variation in volume and weight per acre and formulation. These variables may change due to area, severity of problem, type of equipment, or weather conditions at the time of application. Correct timing of application is probably the most important factor of any pesticide application. Applications per year range from 1-6 for herbicides, 1-15 for insecticides, 1-2 for defoliants, and 1 for fungicides and seeding.

Classification of Herbicides [1,2]

A. Foliar-Applied - herbicides that effectively kill plants by contact with their foliage.

   1. Systemic - herbicides that are absorbed by the plant foliage, then move in the transport system to exhibit their toxic effect at a site away from the point of absorption.

Table 1. Chemicals Used In Aerial Application [3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20]

Chemical	Forml/	Crop	Applic./ Year	Chemical/Acre	Mix Gal./Acre	Mix lbs./Acre
Herbicide:						
Treflan	EC,G	Cotton	1-2	1/4-1/3 gal.	3-10	25-85
		Soybeans	1	1/4 gal.	5-10	40-85
2,4-D	WP	Corn	1	1/4-1/3 pt.	1-10	8-85
		Rice	2	3 pts.	1-10	8-85
		Sorghum	1	2/3-1 pt.	1-10	8-85
		Wheat	1	1/2-1 1/4 pt.	1-10	8-85
Zorial	WP,G	Cotton	1	1/2-1 lb.	8	68
Probe	WP	Cotton	1	1/2-1 1/2 lb.	8	68
Sencor	WP	Soybeans	1	.3-.7 lb.	8	68
Propanil	EC	Rice	2	3-6 lbs.	10	85
Alachor	EC,G	Sorghum	1	1/5-1/4 gal.	2-3	16-25
		Corn	1	1/4-3/4 gal.	3	25-30
Insecticides:						
Toxaphene	EC,WP	Cotton	9-15	1/8-1/4 gal.	1-2	8-20
		Soybeans	2-5	1/8-1/4 gal.	1-2	8-20
Methyl Parathion	EC,WP	Soybeans	2-5	1/4 gal.	1-5	8-45
		Cotton	9-15	1/4 gal.	1-5	8-45
Parathion	EC,WP,G	Rice	2	1/5-1 1/5 pt.	5-10	40-85
		Wheat	1	1-2 pts.	1	8.5
		Corn	2	1/5-1/4 pt.	2-5	17-45
		Sorghum	2	1 pt.	1-2	8-18
Carbaryl	WP,G	Corn	1-2	1/4-1/3 gal.	2-5	16-45
		Soybeans	2-5	1/4 gal.	1-2	8-18
Fungicides:						
Benlate	EC	Soybeans	1-2	1/2 lb.	5	42
Defoliants:						
Def.	EC	Cotton	1-2	1/5-1/3 gal.	1-5	8-45
Seed:						
Rice		Rice	1			120-170
Wheat		Wheat	1			80-140

1/ Formulation of Chemical

2. Contact - herbicides that affect only those areas of immediate contact.

B. Soil-Applied - herbicides that effectively control weed species by soil application.

1. Non-persistent - chemicals usually dissipate within a period of a few days to a few weeks

2. Persistent - may remain toxic to plants for from several months to as long as one or more years

C. Selective - herbicides that kill particular plants

D. Non-selective - herbicides that kill all vegetation

Pesticide Formulations [1,2,3]

A. Soluble Salts (SS) - Purchased either in dry or liquid form. These are easy to use because high solubility eliminates the need for agitation to maintain a uniform distribution in the spray equipment.

B. Emulsifiable Concentrates (EC) - the toxicant is dissolved in a solvent then an emulsifier added. Bypass agitation must be used, in addition to initial agitation, to keep them uniformly mixed.

C. Wettable Powders (WP) - wetting agents are added to the powder to cause rapid wetting and dispersal in the water carrier. Normally greater amounts of water and mechanical agitation is required to prevent the powder from settling out.

D. Granular (G) - the dissolved chemical is sprayed into or mixed with a carrier such as clay. To be classified as a granule 98% by weight must pass through a 15 mesh screen and no more than 5% pass through a 30 mesh screen. These granules will roll off foliage and fall to the ground.

Many of the chemicals are designed for use on only one crop, whereas others may be used on several crops. Some may be mixed (herbicide and insecticide) for one application, whereas others may be applied by ground equipment only. Each chemical carries its own restrictions and each state has additional restrictions.

III. ACRES HARVESTED FOR VARIOUS CROPS

The total United States acreage of most crops has increased over the past few years as a result of improved farming methods. Table 2 indicates the United States total acreage for six of the major crops for 1970-1975. Tables 3 and 4 are included to show the distribution of acreage over seven of the major states. Also, in Table 3 the percent of United States total acres is included in these states and the percent of United States total acres treated by air.

The literature did not give an average field size for the crops considered in this study. The professional workers in the various agricultural disciples were only able to give various ranges for field sizes. For aerial application, field sizes usually were over 40 acres, but often were as high as 1,000 acres.

Table 2. Total U. S. Acres Harvested, 1970-1975 [21]

YEAR	COTTON	RICE	WHEAT	CORN	SOYBEANS	SORGHUM
	(1000 Acres)					
1970	11,155.0	1,814.7	43,564	57,358	42,249	13,568
1971	11,470.9	1,817.9	47,674	64,047	42,071	16,301
1972	12,983.8	1,817.9	47,284	57,421	45,698	13,368
1973	11,970.2	2,170.2	53,869	61,894	55,796	15,853
1974	12,566.2	2,536.0	65,613	65,357	52,368	13,876
1975	8,796.0	2,802.0	69,656	66,905	53,606	15,484

Table 3. Acres Harvested by State - 1976 [10]

	ACRES (1,000)/STATE								
crop/state	CA	TX	OK	AR	LA	MS	FL	% of US TOTAL	% of US TOTAL TREATED BY AIR
Cotton	1120	4508	335	950	560	1470	7	40.8	60
Rice	420	508	---	847	568	144	---	99.4	95
Wheat	940	4700	6300	710	35	180	22	18.2	20
Corn	480	1620	115	53	109	236	560	3.8	10
Soybeans	----	347	240	4320	2120	3250	265	21.3	10
Sorghum	231	6750	950	333	49	74	---	47.7	40

Table 4. Acres Harvested by State, 1973-1975 (1,000 Acres) [21]

	COTTON			RICE			WHEAT			SOYBEANS		
STATE	1973	1974	1975	1973	1974	1975	1973	1974	1975	1973	1974	1975
CA	942	1238	875	401.0	467.0	525.0	572	750	1001	----	----	----
TX	5200	4400	3900	549.0	562.0	548.0	3400	3300	5700	425	261	370
OK	526	547	295	-----	-----	-----	5260	6400	6700	200	219	237
AR	975	1130	680	533.0	725.0	882.0	217	400	520	4650	4300	4700
LA	520	635	310	620.0	660.0	658.0	18	30	25	1580	1760	1820
MS	1340	1710	1100	62.0	108.0	171.0	100	162	185	2750	2500	3120

IV. GROUND VS. AIR

A. Ground vs. Air - Crops

Cotton [3,5,6,7,8,10,12,14,16,17,18,19]

In the production of cotton, most preplant herbicides (Treflan, Cobex) require incorporation into the soil; therefore ground equipment is needed. The application of these herbicides is normally done in connection with ground preparation for planting. A spray boom is mounted on the tractor or other equipment such as a disk, so that land preparation and application of these herbicides is done with one trip over the field. The application of pre-emergence herbicides (Cotoran, Zorial) is done at planting with spray attachments used on the planter. Post-emergence herbicides (MSMA, Probe) are applied after the cotton plant has emerged. This is normally done with spray nozzles attached to a cultivator and directed at the base of cotton plant. These are recommended methods of application, but conditions may require the use of aerial application.

Insecticides and defoliants are applied primarily by aerial application. These two chemicals account for about 80 percent of the total air time spent in cotton production. The following is a national breakdown for cotton on the percentage of total aerial application time for each operation:

[10] Application	% of Total Aerial Application Time
Insecticide	69.7
Defoliant/Dessicant	11.3
Herbicide	3.0
Fertilizer	0.6
Miscellaneous	2.7
Unattributed	12.7
	100.0

Soybeans [3,5,6,7,8,10,12,13,15]

The application of chemicals in soybean production is very similar to cotton. A larger percent of the aerial application in soybeans is attributed to herbicides. Fungicides are used in soybean production and make up about 10% of the air time in soybeans. Defoliants comprise a smaller percentage in soybeans than in cotton. The following is a national breakdown for soybeans on percentage of total aerial application time for each operation:

[10]

Application	% of Total Aerial Application Time
Insecticide	40.4
Herbicide	26.2
Fungicide	10.2
Defoliant/Dessicant	4.3
Fertilizer	1.5
Seeding	1.5
Miscellaneous	5.4
Unattributed	10.5
	100.0

Rice [3,5,9,10,12,22]

Rice production requires the field to be flooded during the time most chemicals are applied. This contributes to 95 percent of all rice acreage in the U. S. being treated by air. Planting can be done by ground equipment, but most is done by air. After planting, the following is a normal sequence of aerial applications used in Mississippi.

[5]
Apply herbicide (Propanil)
Apply herbicide (Ordram)
Apply fertilizer (Urea)
Apply herbicide (2, 4, 5T)
Apply fertilizer (Urea)

These applications are made during a time period of about one month.

The following is a national breakdown for rice on percentage of total aerial application time for each operation:

[10]

Application	% of Total Aerial Application Time
Feitilizer	40.2
Herbicide	19.9
Seed	14.9
Insecticide	5.0
Fungicide	0.7
Unattributed	19.3
	100.0

B. Ground vs. Air - Costs

Table 5 shows a nationwide average of costs per acre for custom application of pesticides on three of the major crops.

Table 5. Expenditures Per Acre For Custom Pesticide Application, Nationwide Average, 1971. [1]

Crop	Ground		Air	
	Spray	Granular	Spray	Granular
Cotton	1.81	5.47	2.72	8.38
Soybeans	1.19	1.40	1.25	5.90
Rice	1.94	----	1.75	1.04

Table 6 gives the aerial application costs for applying the various pesticides, fertilizers and seed in Mississippi. The different prices for insecticides and herbicides are due to larger amounts of water applied per acre or the increased care that must be taken in the application of these special chemicals.

Table 6. Summary of Aerial Application Costs, Mississippi, 1978. [5,6,7,8,9]

Application	Cost Per Acre Dollars	Cost Per 100 Pounds Dollars
Fertilizer	----	2.50
Insecticide	1.00	----
Lannate	1.65	----
Defoliant	1.65	----
Seed	----	2.50
Herbicide	1.65	----
2, 4-D	3.50	----
2, 4, 5-D	3.50	----
Propanil	3.00	----
Ordram	2.00	----

Table 7 shows the cost of machinery used for ground application of chemicals. The costs per acre in Table 7 are used in Table 8, which shows the cost of applying some of the chemicals by ground methods.

C. Ground vs. Air - By State

Illinois [23]

Table 9 shows the total acres treated with insecticides and the percent attributed to aerial and ground applications, with ground applications divided into commercial and individual. Table 10 indicates the total acres treated and acres of various crops treated by aerial applications.

Table 7. Cost of Machinery for Ground Application, Mississippi, 1978 [5,6,7,8]

	Performance Rate per Acre	Length of Life	Average Annual Use	Est. 1978 Price	Repair Costs % of New Cost	Direct Costs Per hr.	Direct Costs Per acre	Fixed Costs Per hr.	Fixed Costs Per acre
	Hours	Years	Hours	Dollars	%	----------Dollars----------			
Sprayer - high clearance - 14 row	.08	8	350	15,500	80	5.46	.44	7.53	.60
Grain Drill - 12 feet	.24	10	100	3,540	70	2.48	.59	5.13	1.23
Grain Drill - 32 feet	.09	10	100	10,600	75	7.95	.72	15.37	1.38
Liquid Fertilizer App. 8-Row	.08	8	150	4,300	80	2.87	.23	4.87	.39
Spin Spreader 300 bu.	.10	8	100	5,200	80	5.20	.52	8.84	.88
Sprayer - Tractor Mounted - 21 feet	.18	8	200	1,300	100	.81	.15	1.10	.20

Table 8. Cost Per Acre of Ground Application, Mississippi, 1978 [5,6,7,8]

Application	Tractor Direct Cost	Tractor Fixed Cost	Equip. Direct Cost	Equip. Fixed Cost	Labor	Total
Liquid Fertilizer	.31	.42	.23	.39	.42	1.77
Granular Fertilizer	.38	.52	.52	.88	.26	2.57
Insecticide	.00	.00	.44	.60	.21	1.25

Table 9. Percent of Total Field Crops Treated With Insecticides By Commercial and Private Applicators, Illinois. [23]

Year	Millions of Acres Treated With Insecticides	Percent of Total Acreage Treated		
		Air	Ground Application	
			Commercial	Individual
1968	7.1	7	13	80
1969	7.9	5	15	80
1970	7.4	5	16	79
1971	6.8	5	14	81
1972	6.8	4	15	81
1973	7.2	16	20	65
1974	7.0	9	19	72
1975	7.3	9	19	72
1976	8.2	5	16	79
1977	8.6	9	12	79
Average	7.4	7	16	77

Table 10. Acres of Field Crops Treated with Aerial Applications of Insecticides, Illinois, 1968-77 [23]

Year	1000's of acres treated					
	Total Acres all crops sprayed by air	Corn	Soybeans	Forages	Small Grain	Sorghum
1968	515	393	64	25	33	--
1969	956	878	30	15	33	--
1970	341	260	37	31	13	--
1971	415	282	45	39	34	15
1972	265	142	12	30	78	3
1973	1,114	334	715	38	10	17
1974	523	393	28	65	30	7
1975	927	652	62	140	70	3
1976	1,508	1,268	100	106	33	1
1977	1,458	1,002	340	88	21	7
Average	802	560	143	58	36	5

The following data have been included to summarize other aerial application operations in Illinois.

Fertilizer - 25% of all nitrogen applied to wheat is by air
- 1% of all nitrogen applied to corn is by air
- less than 1% of all micronutrients applied to beans is by air

Fungicide - 250,000 to 300,000 acres treated by air

Herbicide - approx. 3% of all crops treated by air

Seeding - less that 1% of wheat is seeded by air

Aerial app. Cost (insecticide) - $2.00 to $2.50 per acre

California [24]

The following Data show the total pesticide used and method of application in California for the year 1977.

Total Pesticides Used

Applications	Pounds Used	Acres Treated
309,806	120,838,598.61	19,315,896.71

Total Acres Treated

Air	Ground	Other
14,015,478.55	5,107,387.15	191,420.29

Mississippi [25]

The information in Table 11 is the result of a recent survey of agricultural aircraft operators and professional workers in agricultural related disciplines, conducted by the Agricultural Aviation Board of Mississippi.

Table 11. Acreage in Mississippi Receiving Treatment by Aerial Application [25]

CROP	TOTAL ACRES	ACRES TREATED	PERCENTAGE OF TOTAL ACREAGE TREATED BY AIR	APPLICATIONS/ YEAR
Cotton	1,470,000	1,396,500	95%	12
Soybeans	3,250,000	1,625,000	50%	3
Wheat	180,000	45,000	25%	3
Rice	144,000	141,120	98%	4
Sorghum	45,000	22,500	50%	1
Timber	16,775,000	110,146	.66%	1

Summary

Comparing ground application to air application is not simply a matter of which is more economical, but more of which can be used under certain conditions. As in cotton production, some herbicides must be sprayed under the cotton, therefore requiring the use of ground equipment. Rice fields, on the other hand, must be flooded, requiring aerial application. Timing and weather conditions may require aerial applications for jobs that are normally done by ground.

V. FERTILIZERS

Fertilizers are playing a larger role in agriculture, due to increased populations and a need for greater yields per harvested acre. The use of fertilizers has made a significant increase in yields and is credited with 30 to 40 percent of our total food production. [26] Table 12 shows the USDA estimates of average yields in 1980 compared with 1968.

Table 12. 1968 Acre Yields vs. 1980 Projections [26]

Crop	1968	1980	Percent Increase
Wheat, bu.	30.70	35.00	14
Rice, lbs.	4290.00	5700.00	33
Feed Grains, tons	1.80	2.40	33
Peanuts, lbs.	1743.00	2470.00	42
Cotton, lbs. lint	436.00	560.00	28
Hay, tons	2.06	2.30	12
Corn, bu.	80.40	109.00	36
Soybeans, bu.	26.20	31.00	18
Grain Sorghum, bu.	52.80	76.00	44

Fertilizers are similar to pesticides, in that there is no standard application method to follow for a specific crop. Nitrogen, phosphate and potash are the most common, with nitrogen being the major one of the three. Table 13 shows typical forms of fertilizers used for various crops.

Table 13. Typical Fertilizers Used For Various Crops [5,6,7,8,10,22,27,28]

Crop	Fertilizer
Cotton	Anhydrous Ammonia
	Urea, Liquid
	Ammonium Nitrate
	13-13-13 B
	8-24-24
	0-24-24
Soybeans	0-24-24
Rice	Urea, Solid
	Phosphates
	Sulfate of Ammonia
	Zinc Sulfate
Wheat	Ammonium Nitrate
Sorghum	Anhydrous Ammonia

Although two crops may need a certain amount of nitrogen, they may require different sources. Cotton and rice, for example, require large amounts of nitrogen. Ammonium nitrate is a satisfactory source of nitrogen for cotton, but results in large losses in the gaseous form when applied to the flooded rice fields. Other crops may not require nitrogen, but need phosphate and potash. Corn requires larger amounts of fertilizer if grown for silage than if grown for grain.

The use of fertilizers has made tremendous increases and, according to USDA projections, will continue to increase. Table 14 shows the amounts of commercial fertilizers consumed by various states and the U.S. total for 1951 and 1975.

Table 14. Commercial Fertilizers Consumed (Tons) [21]

State	1951	1975
AR	362,311	577,659
CA	1,637,440	3,756,097
LA	322,580	573,131
MS	762,276	762,832
OK	147,545	652,411
TX	588,562	2,215,052
U.S. Total	22,467,276	42,508,030

Table 6 and 8 give the cost of application for the different methods of fertilizer applications.

VI. FOREST

The forest industry in the U. S. is based primarily on coniferous species, with southern pines in the southeastern region and various species of pines, spruce, fir, hemlock, cedar, and redwood in the region from the Rockies to the Pacific Coast. Table 15 shows the total acres of forest in the U. S. by regions.

Table 15. Forest Land In U. S., 1970 [21]

Region	Total Acres (1,000 Acres)
New England	33,410
Middle Atlantic	53,196
Lake	53,959
Central	45,928
North	186,494
South Atlantic	49,496
East Gulf	43,478
Central Gulf	51,819
West Gulf	67,090
South	211,884
Pacific Northwest	172,553
Pacific Southwest	44,382
Northern Rocky Mountain	55,853
Southern Rocky Mountain	82,380
West	355,169
All Regions	753,549

Aerial application of pesticides and seeding have become an important part of forest management. In operations such as seeding, 1500 to 2500 acres can be covered aerially in a day, whereas only 15 to 40 acres can be covered by ground. Many areas, normally less than 200 acres, are treated by ground methods because of their irregular shape. Even though airplanes are used, helicopters are often desirable because of their greater maneuverability. In seeding operations, helicopters can cover up to

2,500 acres per day with a swath width of 99 feet. Fixed-wing aircraft cover up to 1,500 acres per day with a swath width of 66 feet. Tractor mounted sowers cover 40 acres per day with a swath width of 40 feet. Up to 15 acres per day can be covered with a hand-operated cyclone seeder with a swath width of 16 feet. [28]

Herbicides such as 2, 4-D; 2, 4, 5-T; silviex; picloram and dicamba are used in reforestation of lands. These herbicides are used to kill grass and brush that have dominated lands. They can also be used to control grass in desirable trees, but are not very effective in killing grown, undesirable trees. Herbicides are also used to remove brush along power and telephone lines, railroad-rights-of way, highways, stream bands, and canals. The normal rate for aerial application is 1 to 3 pounds of active ingredient mixed with 5 to 10 gallons of water. [2]

Aerial application is probably the most economical method of applying fertilizers to large areas of forest. The cost for applying fertilizers aerially range from $10 to $30 per acre, depending on the type and quantity applied, type aircraft used and distance to the area. Fertilizers can be applied with seed in one operation or to standing forest. Slowly soluble forms of fertilizers are popular in forest fertilization because they supply nutrient needs as the trees grow and may last from 5 years up to 40 years. Another consideration of forest fertilization is the fact that most of the nutrients taken from the soil are returned through leaf litter. [28]

VII. FUTURE MISSIONS

No-Tillage and Double Cropping [29]

The no-tillage method of farming started in the early 1960's and has become an effective practice. This method of farming has been made possible by the use of modern chemicals for controlling weeds, rather than using tractors and cultivation. Less machinery and lower power requirements are needed for this method. No-tillage requires stricter management practices, but offers higher yields, reduced production cost, less erosion, less soil compaction, better timing in planting and harvesting and allows land that was not suitable for production to be put into production. Table 16 shows how the no-tillage acreage increased from 1969 to 1971.

Table 16. No-Tillage Estimated Acreages in Selected States [29]

State	1969 Total	1971 Total
Illinois	6,000	40,000
North Carolina	30,000	90,000
Indiana	2,000*	25,000
Ohio	8,000	100,000
Virginia	20,000	180,000
Tennessee	35,000	80,000
Kentucky	150,000	420,000
Iowa	3,000	12,000
Arkansas	5,000	28,000
Missouri	2,500	30,000
Kansas	100	4,000
Nebraska	900	3,000
Canada	2,000	14,000

*Southern Indiana

Double-cropping, a system of planting two crops on the same land in one year, has expanded as a result of the no-tillage method. Double-cropping can be accomplished by aerially seeding one crop in a standing crop ready to be harvested. Planting with ground equipment is also done immediately after harvesting one crop. Even though most double-cropping is over a period of one year, a combination such as corn, barley, and soybeans can be used to get three crops in two years. Many combinations are available, but soybeans double-cropped with small grain is probably the most widely-used in the United States.

These two methods of farming will probably play a more significant part in agriculture with stricter regulations imposed on pollution control.

Planting of Tree Seedlings [1]

Tree seedlings have been planted aerially with ballons, helicopters, and airplanes, but the most successful attempt was in 1971. Seedling roots were put in molds, filled with soil, wrapped in polyethylene film and frozen. They were then placed in polyvinylchloride pipe, with special fins and dropped from a height of 400 feet. The seedlings penetrated the soil 6.5 inches, splitting the casing and allowing the roots to egress.

These seedlings can be planted at a rate of 160,000 per day per airplane, with a cost of seven cents per seedling. Using ground methods, 700 per day per man can be planted at a cost of eight cents per seedling.

Pesticides and Fertilizers Applied Through Irrigation [26]

Methods have been developed to apply foliar pesticides and fertilizers through sprinkler irrigation systems. Currently this approach is not widely used, but it is included in this report to show developments that might reduce the desirability of aerial application of pesticides and fertilizers.

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APPENDIX B

AIRWORTHINESS AND OPERATING REQUIREMENTS

FOR

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C-4

A regulatory basis for the certification of aircraft has been developed by a series of acts by the U. S. Congress.[1] The Air Commerce Act of 1921, the Civil Aeronautics Act of 1938, and the Federal Aviation Act of 1958 established the mechanism for maintaining certification regulation by designating an administrator with the responsibility and authority for insuring certain minimum air worthiness standards by prescribing appropriate rules and regulations. The certification of agricultural aircraft is governed by the following rules and regulations:

(1) Civil Aeronautics Manual (CAM 8) - Restricted Category

(2) FAA Advisory Circular 20-33B

(3) Federal Aviation Regulations (FAR) Part 23 - Airplane Airworthiness

(4) Federal Aviation Regulations (FAR) Part 21 - Procedural Rules

Many of the current aircraft are certificated in accordance with the standards of CAM 8 Appendix B, or a combination of criteria defined by CAM 8 and FAR Part 23. Others have been certificated on the basis of Part 23 alone. Table 1 is a resume of the certification basis for most of the agricultural aircraft currently in production. Many foreign countries will allow export of normal category aircraft on the basis of reciprocity agreements so that U. S. certification is sufficient. This is not the case for restricted category certification, and additional requirements which are peculiar to the importing-country are frequently imposed. Piper and Cessna have certificated their aircraft in both restricted and normal categories to facilitate export markets.

The provisions of the certification documents are subject to FAA regional interpretation and no mechanism for insuring uniformity of criteria has been established. This results in disparate certification requirements from region to region and suggests the requirement for standardization of criteria developed specifically for agricultural aircraft. It has been reported, for example, that a recent Supplemental Type Certificate (STC) was issued by one FAA region for installation of an elevator servo tab to decrease the stick force gradient in a particular model agricultural aircraft, whereas the stability criteria applied by another FAA region prohibited installation of a similar servo tab by the original aircraft manufacturer.

TABLE 1

CERTIFICATION BASIS

MANUFACTURER	MODEL	TYPE CERTIFICATE NUMBER	CERTIFICATION BASIS
Emair	MA-1B	A6PC	FAR 21-25 (a) (1), May 14,1976 Restricted Category
Cessna	188 Series	A9CE	FAR 21, February, 1965 Restricted Category
			FAR 23, February, 1965, Normal Category
Grumman	G-164	1A-16	CAR 8.10 (a) (1), October 11, 1950, CAM 8, Appendix B-1957
Piper	PA-36	A10SO	FAR 21, Amendement 21-1 thru 21-24, August 31, 1972 Restricted Category
		A9SO	FAR 23, May 31, 1972 Normal Category
Rockwell Commander	S2B, S2C, 600-S2C	2A7	CAR 8.10 (a) (1), October 11, 1950, CAM 8, Appendix B-1957
Rockwell Commander	600-S2D, S-2R	A3SW	CAR 3, May 15, 1956, Amendment 3-1, 3-8

Maintenance requirements, standards and procedures, are specified in Federal Aviation Regulations (FAR) Part 43 - Maintenance, Preventive Maintenance, Rebuilding, and Alterations - for all aircraft operating under the provisions of the Federal Aviation Act of 1958. Experimental aircraft, and amateur aircraft are excluded by Part 43, but agricultural aircraft must be maintained as all other U. S. civil aircraft. Similarly, agricultural aircraft, normal category and restricted category, are covered by the provisions of Federal Aviation Regulations (FAR) Part 39 - Airworthiness Directives. This provides for ad hoc modifications or retrofit of items which affect the airworthiness of aircraft of 12,5000 lbs. and less gross weight. Neither Part 43 nor Part 39 has a direct impact on the design of agricultural aircraft, but each contributes in a favorable way to the orderly and efficient airworthy maintenance of these aircraft.

The Federal Aviation Regulations, Part 91 - General Operating and Flight Rules - and Part 137 - Agricultural Aircraft Operations - define operational requirements for pilots and the operation of aircraft in agricultural applications. These regulations are such that no conditions are imposed on the airplane which directly involve the engineering technology. There are several operational difficulties caused by interpretation of rules concerning use of restricted category aircraft in congested areas which adversely affects the efficient use of agricultural aircraft. These problems, however, are not related to the airplane technology and therefore are considered to be outside the scope of this study.

A review of the certification process has been undertaken to establish the impact of FAA rules and regulations on the design and performance of agricultural aircraft. In particular, certain criteria appear to adversely affect performance and pilot acceptance while providing no significant safety advantage. Several examples are given below to illustrate specific points of concern where the regulatory influence seems to be adverse or where no appropriate regulation is available. The list is incomplete but is representative of opinions received from program managers who have recently been involved in certification of agricultural airplanes.[2]

Stability Requirements - Aircraft stability requirements adversely affect handling qualities and increase pilot workload. The CAM 8 requirement for stick force gradient is that the gradient is "clearly perceptible." Some FAA regional interpretation results in too high stick forces and subsequent pilot complaints. It has been reported that one model aircraft is frequently "field modified" by converting the factory installed anti-servo tab to a servo tab to reduce stick loads at working speeds to acceptable values. Also, instrument approach stability requirements being applied to agricultural aircraft are inappropriate. Excess stability margins result in control forces which are undesirably high and tend to induce pilot fatigue during normal agricultural operations.

Stall Warning - Stall warning criteria pose a special problem to agricultural operations. Current CAM 8 and Part 23 requirements specify a stall warning margin which appears to be too large for agricultural aircraft operations with current stall warning devices. Further, the stall warning margin increases as the aircraft weight increases (for vane type sensors) such that the standard stall warning criteria result in system activation at 10-12 mph above stall at high gross weights. This results in continuous stall warning during pull-up and turn-around in agricultural operations, which is unacceptable to the pilot. It is reported that the stall warning devices are frequently disabled by pilot/operators. New specifications and/or stall warning devices tailored to agricultural requirements are needed.

Spin Criteria - Part 23 spin criteria are not appropriate since fully developed spins are rarely, if ever, encountered in agricultural flying. Stall and post-stall behavior is a far more significant safety factor within the context of agricultural operations which are mostly at altitudes below 500 feet.

Turbine Aircraft - Certification of turbine-powered aircraft must be on the basis of Part 23 since CAM 8, Appendix B, does not include turbine engines. This is a prime example of new technology that is not addressed by existing regulatory requirements for agricultural aircraft. The criteria established by Part 23 specifically apply to passenger aircraft and are not appropriate to agricultural airplanes and the peculiar operating conditions associated with their operation. Regulatory exceptions are possible, of course, but they must be individually negotiated by each manufacturer. Some of the general certification criteria, such as the requirement for inlet de-icing, could be categorically rescinded for turbine ag aircraft.

Large Aircraft - There are no criteria for aircraft weighing more than 12,500 lbs. and/or multi-engined aircraft. Some large aircraft in this category are currently being used in agricultural operations where high volume application rates and large field sizes are involved. It is reasonable to assume that large multi-engined aircraft will be produced as market requirements develop, and an appropriate certification basis will have to be developed.

Some certification requirements result in unnecessary and undesirable design compromises which adversely affect airplane performance and the ability of pilots to perform the required missions. Virtually all of the current regulatory base, standards, rules, and regulations, were developed on the basis of available technology prior to 1950. The entire certification process needs to be reviewed and changed to account for current technology and the mission-dedicated nature of agricultural aircraft. Further, a standardization must be maintained to insure equitable certification costs and uniform airworthiness. Current certification criteria and practices tend to impede the transfer of new technology into production aircraft because of a lack of a regulatory basis for certification of new technology.

It seems clear that a careful review and update of the certification basis for agricultural aircraft should be undertaken. Additionally, a research program should be undertaken in support of changes to regulations in order to establish and validate appropriate criteria and to develop methods and technology where necessary. Recommended research to support possible changes is listed in the following paragraphs in three categories.

1. Flight Control

A research program should be undertaken to investigate problems associated with the flight control of agricultural aircraft within the context of their mission - dedicated use. Analytical, ground-based simulation, and flight test programs should be established to investigate the static and dynamic stability requirements and characteristics with regard to effects on airplane handling qualities. Handling qualities criteria must be established which reflect the special mission application and pilot workload in performing that mission. Programs should be developed to include aerodynamic devices to improve maneuverability and the impact of these devices on controllability, pilot workload, and mission effectiveness. Further, research program should be established to investigate man-machine interface items, such as displays, controls location and arrangement, and cockpit environment with particular regard to the certification impact of such pilot factors.

2. Stall

A research program should be undertaken in support of development of new criteria for stall and post-stall characteristics of agricultural aircraft. Stall warning devices which are appropriate to agricultural applications must be developed as well as criteria to govern installation design. The device and criteria must be tuned to the peculiar operational requirements of the mission; in particular, heavy weight, low speed, low altitude maneuvering. Further, research is needed to develop technology and criteria which results in aircraft stall and post stall (or aggravated stall) behavior which is easily controlled and results in minimum altitude loss. Stable spins and spin recovery are of little significance in agricultural operations.

3. Restricted Category Certification

Research would be undertaken or augmented which would provide better engineering data and methods to allow certification of all agricultural aircraft in the normal category. This could result in a more favorable international acceptance of U. S. agricultural aircraft and ease export problems associated with restricted category airplanes. An extensive VGH data base for all categories of agricultural airplanes is essential to establishing realistic design criteria. The present design criteria are based on 1950 and earlier technology. A research program must include critical review of current technology to evaluate the potential impact of recent developments and new data on existing criteria. Further, gust load factors for agricultural aircraft need to be established in view of current technology and actual conditions encounterd in agricultural operations.

The list of recommended research is certainly not complete, but it is representative of certification problem areas which require additional research to adequately establish criteria and validation data. The research suggestions and problem areas are those most frequently identified by people who have direct experience in the certification process for one or more agricultural aircraft.

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