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AN EVALUATION OF FLEX-WING AIRCRAFT IN SUPPORT OF INDIGENOUS FORCES INVOLVED IN COUNTERINSURGENCY OPERATIONS

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Prepared for

Advanced Research Projects Agency

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FOREWORD

This report details the conclusions drawn from a study of flex-wing vehicles conducted by the Planning Research Corporation under ARPA order 547, Army Research Office contract number DA-31-124-ARO-D-263. The study as actually conducted was quite different from the original concept, which was intended as an evaluation of flex-wing aircraft in support of U.S. forces engaged in military operations.

Early in the program, PRC's efforts were redirected by ARPA toward the problems of indigenous forces performing anti- and counter-surgency actions in underdeveloped countries. The ultimate effect of this redirection was to bring into focus missions and roles whose requirements were more compatible with the performance characteristics of the powered and towed version of the flex-wing vehicles than with the drop glider or homing versions of the towed glider--both of which have potential value to U.S. forces operating in sophisticated combat environments. The precision drop glider, the towed glider with a homing device, and competitive devices such as the steerable parachute were effectively eliminated from further analysis by two factors: first, their application in counterinsurgency operations appeared not to offer improvements in mobility of the magnitude sought by ARPA; and second, they depend in all cases on relatively expensive and sophisticated air vehicles for their utility.

This study was performed as a team effort under the direction of M. Fishbein, Project Manager. Members of this team and their areas of research were R. A. Wise and F. J. Berberich, operational environment; E. Moness, a consultant, aircraft characteristics and performance analysis; S. D. Newland and O. Hansen, cost analysis; and Dr. M. S. Schaeffer, mathematical modeling and cost-effectiveness analysis.

ABSTRACT

Cost-effectiveness evaluations were made of several versions of flex-wing aircraft in support of civic action and counterinsurgency operations performed by the indigenous forces of underdeveloped nations.

Powered flex-wing aircraft were compared with light fixed-wing and rotary-wing aircraft presently in or planned for inclusion in U.S. Army aviation inventories. These same aircraft were considered in the performance of routine logistic functions, alone and as part of towed flex-wing glider systems.

The cost-effectiveness analyses were accomplished through simple models of situations derived from an analysis of four underdeveloped countries. No attempt was made to combine the several results into one overall measure of cost-effectiveness or to define an optimum system to support the forces of a particular country.

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I. SUMMARY

The results of this study recognize two distinct types of flex-wing vehicles: the powered flex-wing utility aircraft, and the towed flex-wing glider.

Competing conventional aircraft employed in the operations and cost-effectiveness comparison with the powered flex-wing were the Beaver and Otter fixed-wing utility aircraft and the LOH-5A and UH-1D helicopters.

In analyzing the role of the towed flex-wing glider in support of or in enhancing the operational performance capabilities of conventional aircraft, two basic (payload) sizes were examined, a 2,000-pound-payload glider operating in combination with the Beaver, the Otter, and the LOH-5A; and an 8,000-pound-payload glider towed by the UH-1D helicopter.

For the powered flex-wing utility aircraft, the most significant parameter in establishing a superiority in cost-effectiveness (dollars/flying hour) with competing conventional aircraft was the unit or flyaway cost, based on accepted values of life expectancy (5 years) and quantities purchased (1,000 units). On the other hand, the towed glider systems were basically insensitive to the flex-wing glider unit cost parameter because of the overpowering effect of the cost of the towing aircraft.

Generally, the cost-effectiveness results obtained from all the towed glider systems were disappointing; in only two cases did the towed glider system perform better than the towed vehicle carrying its normal payload. One, the LOH-5A towing a flex-wing glider, showed that this system was slightly superior to the helicopter operating alone, when hauling cargo short distances; i.e., 25 n.mi. The other, the UH-1D in the towing configuration, showed an improved effectiveness over the UH-1D operating alone, both for short- and long-distance hauling. However, in no case was the improvement of such a significant nature as to recommend the towed glider configuration over the towing

craft operating alone. One exception to the above conclusion could be drawn from the occasional requirement to haul an oversized object; here the towed glider with its open sides and flat cargo deck has an indisputable advantage, albeit not measurable by any of the cost-effectiveness parameters employed in this study.

The poor showing of the towed glider system is clearly due to the large increment in drag imposed on the combination by the flex-wing configuration. Improving the aerodynamic configuration of the present type of flex wing would, to be sure, reduce the drag horsepower required, but not without an attendant increase in fabrication complexity, and control and stability problems. Intuitively, the gain in operating performance to be obtained from this improvement in aerodynamic cleanness--i. e., increased L/D--would not improve the cost-effectiveness ratios by a significant amount. Furthermore, the prospect of overloading any one of the tow-craft offers such gain in operating performance, without adding to the inventory, that it should not be overlooked as a worthy competitor to the towed glider system.

Another important conclusion to be drawn from this study is the relative insensitivity of cost-effectiveness to aircraft performance operating in the type of environments and situations developed in this report. With this insensitivity to performance, the use of conventional aircraft, in lieu of the slow-speed, short-range capability of the powered flex-wing utility vehicle, offers no measurable advantages. This is borne out in the results of the cost-effectiveness analysis for both civic action and military missions.

In civic action roles, the low unit cost of the powered flex wing makes its cost-effectiveness superior to that of the conventional fixed-wing aircraft, and orders of magnitude better with respect to helicopters when the maximum cost ratios (i. e., PRC estimates) are used. Using the minimum cost ratios as a basis for establishing cost-effectiveness (i. e., the higher cost data submitted by Ryan), one finds that the powered flex-wing utility aircraft enjoys but a nominal advantage over the conventional fixed-wing vehicles for many missions. The most significant advantage of the powered flex-wing utility vehicle is found in the cost-effectiveness comparison with helicopters; this is because of the high unit cost of this system and its application to missions not optimal to their (helicopter) operational capabilities.

The composite results of most of the missions of a military character studied in this evaluation reveal the powered flex-wing utility vehicle to be slightly better than conventional fixed-wing aircraft when the cost-effectiveness is based on the conservative, minimum cost ratios.

Only for the rapid-reaction and routine resupply missions did the conventional fixed-wing aircraft show a marginal edge in cost-effectiveness over the powered flex-wing aircraft, using the conservative, minimum cost ratios. The use of the less conservative cost ratios developed by PRC gives the powered flex-wing utility vehicle a slight advantage over the conventional fixed-wing aircraft.

For some selected military roles, such as troop reinforcement, command and control, artillery direction, and convoy control, the use of the powered flex-wing utility vehicle offers substantial advantages over conventional fixed-wing aircraft, and superior performance (i. e., cost-effectiveness) over the use of helicopters.

II. INTRODUCTION

A. General

The transportation systems of underdeveloped countries are primitive by U.S. standards. Their populations are heavily rural and--while villages are not generally far from market towns that serve as area communication centers--relatively inaccessible to government agents on a routine basis. During certain seasons only air modes of transportation are capable of offering any communication at all between villages and towns.

The problems of countering insurgency are closely tied to these communication shortages. Education, medical assistance, and protection are always difficult, sometimes impossible, to provide. Roads and railroads will not be adequate for years. Aircraft may well be a necessity if discontent is to be controlled and eliminated.

The interest of the United States in these problems is not an idle one. Recent history provides many examples in which unrest in underdeveloped nations has grown to such proportions as to produce a confrontation between international powers. On several occasions, U.S. participation has been forced at an intense and expensive level. Should such participation be required simultaneously in several areas, the United States would find it difficult to be responsive.

The solution to the problem may lie in providing indigenous governments the tools required to fight insurgency effectively without significant outside help. At early stages of insurgency, the mobility inherent in aviation is unquestionably one of these tools. And since sophisticated aircraft may not be required to fight an unsophisticated adversary, the cost issue is likely to be the paramount one.

The Rogallo or flex-wing concept consists essentially of three configurations: (1) a powered version that leads to a cheap, low-speed, "dirty" airplane; (2) an easy-to-tow glider capable of carrying odd-size loads because of its open construction and flat-bed cargo deck; and (3) a collapsible glider (PDG) adaptable to air launch from a high-flying aircraft and competitive with the steerable parachute and similar modes of aerial cargo delivery.

The first two configurations are potentially useful as cheap air transportation or as economical ways of supplementing existing aircraft. Their utility to indigenous forces will be explored in the body of this report. The PDG, on the other hand, is a special-purpose technique of interest primarily because of the stand-off and homing capabilities it can provide. An analysis of operational environments of interest to indigenous counterinsurgency forces did not lead to a sufficient number of PDG roles to merit its inclusion in this study. Similar considerations led to the elimination of the homing version of the towed flex-wing glider as a subject for evaluation.

B. Study Approach

In the following pages the study methodology and results are described. In brief, the approach selected was as follows:

1. Several underdeveloped countries were selected for analysis. Maps of these countries were drawn and population centers and centers of government located. Roads, airports, and communications were identified and terrain and atmospheric environments investigated.

2. A variety of publications and historical records were consulted and a set of civic actions and military operations appropriate to counterinsurgency was constructed. This set of activities and the results of the map analysis were used to develop an operational environment and a model province, in which context the remainder of the study was conducted.

3. The above analyses led to the establishment of roles and missions for aviation. Those flex-wing configurations with performance characteristics matching the operational requirements were then identified. In a similar manner, conventional, competitive systems were selected on the basis of compatible performance characteristics.

4. Army and Air Force publications and information obtained from manufacturers were used to determine the performance and cost parameters of the selected systems.

5. Models of the missions were constructed and cost-effectiveness comparisons of alternative systems were performed. The models were intentionally simplified so that the contributions of the basic cost and performance parameters could be clearly identified. Furthermore, the evaluation was carried out under the assumption that the aircraft of interest will be operated and maintained by indigenous forces, as contrasted with the present situation in South Vietnam in which the Army of the Republic of Vietnam receives extensive support from United States military aviation.

III. AIRCRAFT MISSIONS AND ROLES

In order to identify likely areas of utility for flex-wing vehicles and to establish realistic performance demands to be made, a detailed operational environment was desired. The term, operational environment, is used here to denote collectively the general military-political context, the physical and cultural characteristics of the area of operations, the roles and functions for which this class of aircraft seems suited, and finally a series of representative aircraft tasks described in discrete terms of payload, distance, time, and other operating constraints.

Within this general context, a distinction may be drawn between two broad areas of potential utility. The first such area covers a wide range of applications which might be termed civic action. This general class includes the transportation tasks associated with government programs of public health, public education, agricultural improvement, and resettlement, as well as the internal administrative transportation required in conducting the routine business of government. These areas are relevant to the study on two counts. First, the represent programs that are essential elements in a national counterinsurgency campaign, and, second, these programs are commonly supported by military resources.

The second area encompasses those routine military tasks which are typical of counterguerrilla operations. This category is representative of a more advanced stage of insurgency; in some ways, it corresponds to the 1964-1965 period in South Vietnam. However, the roles and missions depicted under this category are in most cases equally applicable to the actions required of national police and other para-military forces during the early stages of an insurgency.

The civic and military applications appropriate to counterinsurgency are to a certain extent a function of the particular environment in which they take place. The political and physical environment used as a context is a model based on a survey of four countries--Thailand, Nigeria, West Pakistan, and Colombia--which were selected as being representative of underdeveloped areas in which there is a reasonably presumptive threat of insurgency. The distances, frequencies, and payloads used in the cost-effectiveness analyses are derived from this model province, which influences also the civic action missions defined and the military deployment assumed.

The civic action applications considered are based on similar activities being conducted in widely scattered parts of the world, as reported in publications of the Agency for International Development, various military journals, and the work of private researchers. The selected applications also include roles for which no specific precedent has been found but which appear to PRC as reasonable areas for investigation. Two assumptions were required for the determination of these applications:

- In the context of the study, the most significant activity connected with civic action programs is that which takes place at the lower levels of publication administration (i.e., the province, the district, and the township).

- Aircraft of the general class to be evaluated will be used extensively in civic action programs owing to the primitive nature or the vulnerability of surface transportation.

The characterization of the military operations incorporated herein is based on two main sources. These are, first, historical records of post-World War II counterinsurgency campaigns in Malaya, Algeria, the Philippines, and Vietnam; and, second, current United States military doctrine for operations against irregular forces.

A. The Model Province

The model province (Exhibit 1) is approximately 5,000 square miles in size and has a population of about 40,000 concentrated mainly in the central and western portions. The province is subdivided politically into seven districts. Eighty percent of the population live in rural communities of 100 to 500 people and the economy is predominantly agricultural. These farm communities are in effect satellites of larger market towns, one of which in each district is the seat of government or district headquarters. The provincial capital and district headquarters are connected by a sparse network of semi-improved seasonally unusable roads. The

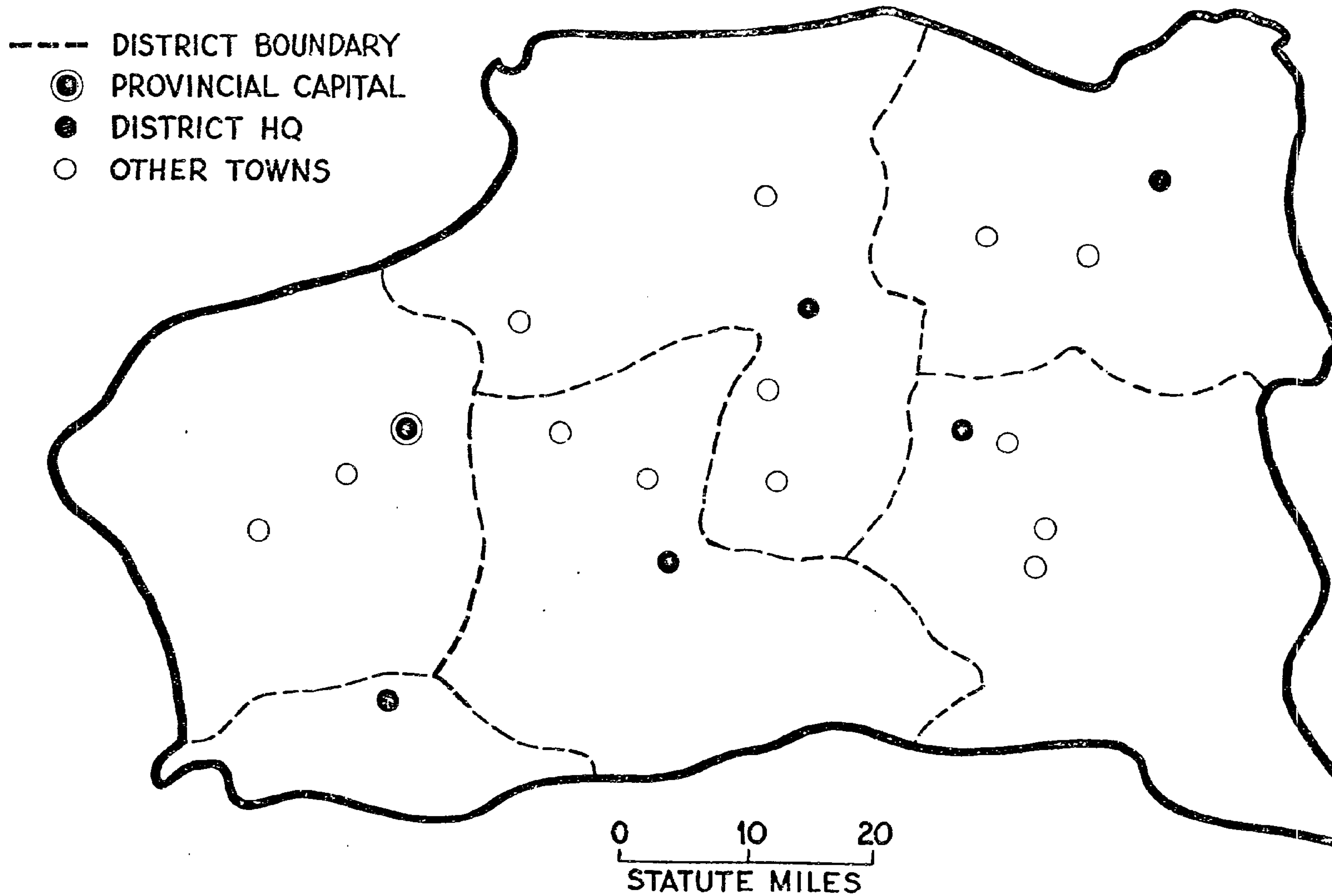

EXHIBIT 1 - MODEL PROVINCE

district headquarters, market towns, and rural communities are connected by cart tracks, which are for the most part suitable for animal-drawn vehicles. The provincial capital, district headquarters, and market towns are also linked by government-operated telephone and telegraph service, used primarily for government business.

The terrain in the central and western portions of the province is level to gently rolling, and is divided about evenly into cultivated land, small groves of trees, and savanna. In the east the ground rises through foothills to heavily forested mountain slopes.

B. Civic Action Applications

Civic action conceived on a broad scale can give rise to an almost limitless number of uses for aircraft of the class under study. For purposes of this evaluation, it is sufficient to identify a relatively small number of applications covering a broad spectrum of nominal distance-payload combinations and hence representing the performance demands associated with a much larger number of conceivable uses for the flex-wing vehicle and its competitors. Seven such applications have been selected and are defined below. In selecting these representative applications, an effort has been made to avoid those which are of marginal utility or are highly speculative and to concentrate on roles which imply extensive utilization of the aircraft for purposes directly related to bolstering national immunity to insurgency.

1. First Application

Requirement: Provincial and district officials must make frequent visits to local centers of population and subordinate units of government to conduct public business and maintain contact with their constituencies. In this role the aircraft must support travel from the provincial capital to district headquarters, between district headquarters, and from district headquarters to other principal towns.

Payload: 360 lbs.[1]

Distance-Frequency Table:[2]

Miles	f
0-5	2
6-10	4
11-15	6
16-20	1
21-25	9
26-30	2
31-35	0
36-40	0
41-45	1
46-50	0
51-55	0
56-60	1

2. Second Application

Requirement: Teams of government information specialists, medical technicians, and intelligence personnel based at district headquarters must visit small communities in areas of intensive insurgent activity, for the purpose of maintaining the government presence, hearing grievances, gathering information, and administering minor medical aid. The typical team consists of five men and is equipped with public address apparatus, supplies of news media, and medical supplies.

[1] All calculations assume the weight of one man to be 180 pounds.

[2] Frequency refers throughout to the number of times the distance occurs in the geometry of the model province.

Payload: 1,500 lbs.

Distance-Frequency Table:

Miles	f
0-5	2
6-10	4
11-15	5
16-20	1
21-25	1

3. Third Application

Requirement: Telephone and telegraph lines connecting principal towns and centers of government must be kept operative to support the public business and provide warning of insurgent activity. Repair teams consisting of the aircraft pilot, and one additional man, with repair tools and replacement supplies will make continuous inspection flights to detect trouble spots and make such repairs as may be feasible. Teams operate from district headquarters. For the purpose of establishing mission distances, the long line segments requiring surveillance are assumed to be as shown in Exhibit 2.

Payload: 400 lbs.

Distance-Frequency Table:

Miles	f
0-5	8
6-10	15
11-15	3
16-20	0
21-25	1

4. Fourth Application

Requirement: In order to bring skilled medical care to the majority of the population, teams of doctors based at district headquarters must make frequent periodic visits to outlying towns. These flights are also used to replenish stocks of medical supplies at local clinics.

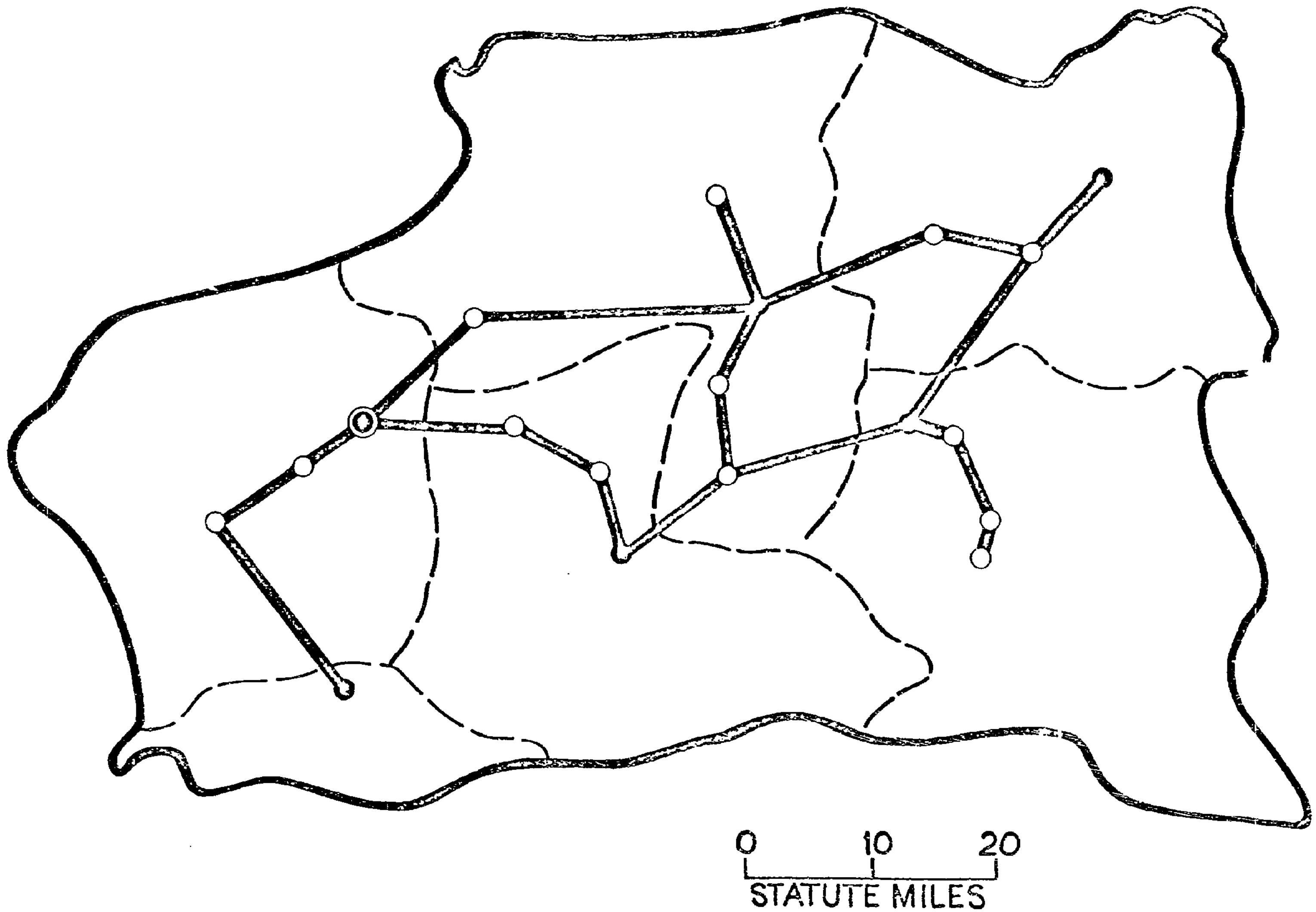

EXHIBIT 2 - TELEPHONE/TELEGRAPH LINE SURVEILLANCE

Payload: 400 lbs.

Distance-Frequency Table:

Miles	f
0-5	2
6-10	4
11-15	5
16-20	1
21-25	1

5. Fifth Application

Requirement. Seriously ill and injured persons requiring modern hospital care must be evacuated to the provincial capital. Missions include both scheduled and emergency flights.

Payload:

Case 1: 180 lbs.

Case 2: 1,080 lbs.

Distance-Frequency Table:

Miles	f
0-5	1
6-10	1
11-15	2
16-20	2
21-25	1
26-30	2
31-35	2
36-40	0
41-45	3
46-50	0
51-55	3
56-60	1

6. Sixth Application

Requirement: Government agricultural experts based at district headquarters must provide county-agent type services to farmers throughout the district, requiring frequent, recurring visits to outlying agricultural communities.

Payload: 180 lbs.

Distance-Frequency Table:

Miles	f
0-5	2
6-10	4
11-15	5
16-20	1
21-25	1

7. Seventh Application

The general requirement is for aerial dissemination of pesticides and insecticides over large areas of the province in connection with government programs for increasing agricultural yields, suppressing insect-borne diseases, and opening new land to productive use.[1]

a. Case 1

Requirement: Spray 150,000 acres of crop land.

Payload: Spray equipment weighing 150 pounds, plus optimum weight of insecticide calculated at 32 pounds per acre.

Rate of Coverage: 60 acres per aircraft per hour.

b. Case 2

Requirement: Spray 75,000 acres of swamp and savanna.

Payload: Spray equipment weighing 150 pounds, plus optimum weight of insecticide calculated at 6 pounds per acre.

Rate of Coverage: 60 acres per aircraft per hour.

C. Military Applications

Insurgent forces in the province are assumed to consist of 1,000-1,500 armed guerrillas supported by a covert civilian apparatus of

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[1] Although the use of defoliants and chemical/biological agents for military purposes is not considered in the evaluation, these uses are analogous to the application described here.

approximately three times that number. An infantry division, consisting of three regiments and supporting troops, has the mission of subduing the insurgents in the province. The organizational structure of the division follows orthodox military lines although the infantry strength--14 battalions--is greater than the more conventional 8 to 10 battalions.

The deployment of the division is illustrated in Exhibit 3, wherein it is assumed that government forces have established virtually unimpaired control of the shaded region. Elsewhere in the province, control of both land and population is in contention and the guerrilla has almost unrestricted freedom of operation as long as he moves in groups of 50 or less. Furthermore, two districts in the province are shown unoccupied. This reflects the commonly encountered situation in which the counter-insurgent forces are not strong enough to mount an intensive campaign everywhere at once. Several features of the deployment merit special mention because of their particular significance with respect to the definition of specific aircraft tasks.

Companies, battalions, regiments, and the division itself have been assigned precise territorial sectors of responsibility. The foci of tactical activity are the combat bases established by each of these elements. At battalion, regimental, and division levels, the combat base consists of the command and control element, combat support units, combat service support units, and a reserve or reaction force of appropriate size. Both short-range and long-range patrols operate extensively in the occupied areas, performing reconnaissance and combat missions. Sectors of responsibility correspond to political subdivisions insofar as possible. Thus, each regiment is assigned a sector corresponding to a district (see Exhibit 4), the division area of responsibility is the province, and military command posts are co-located with the seats of civil government in their respective areas of responsibility.

It is assumed that the duration of the anti-guerrilla campaign will have made it feasible and profitable to construct rudimentary airstrips at company, battalion, and regimental combat bases. The guerrillas are armed with small arms, light mortars, and a few recoilless rifles. Their most effective antiaircraft weapons are 9-mm. and .50-caliber machine

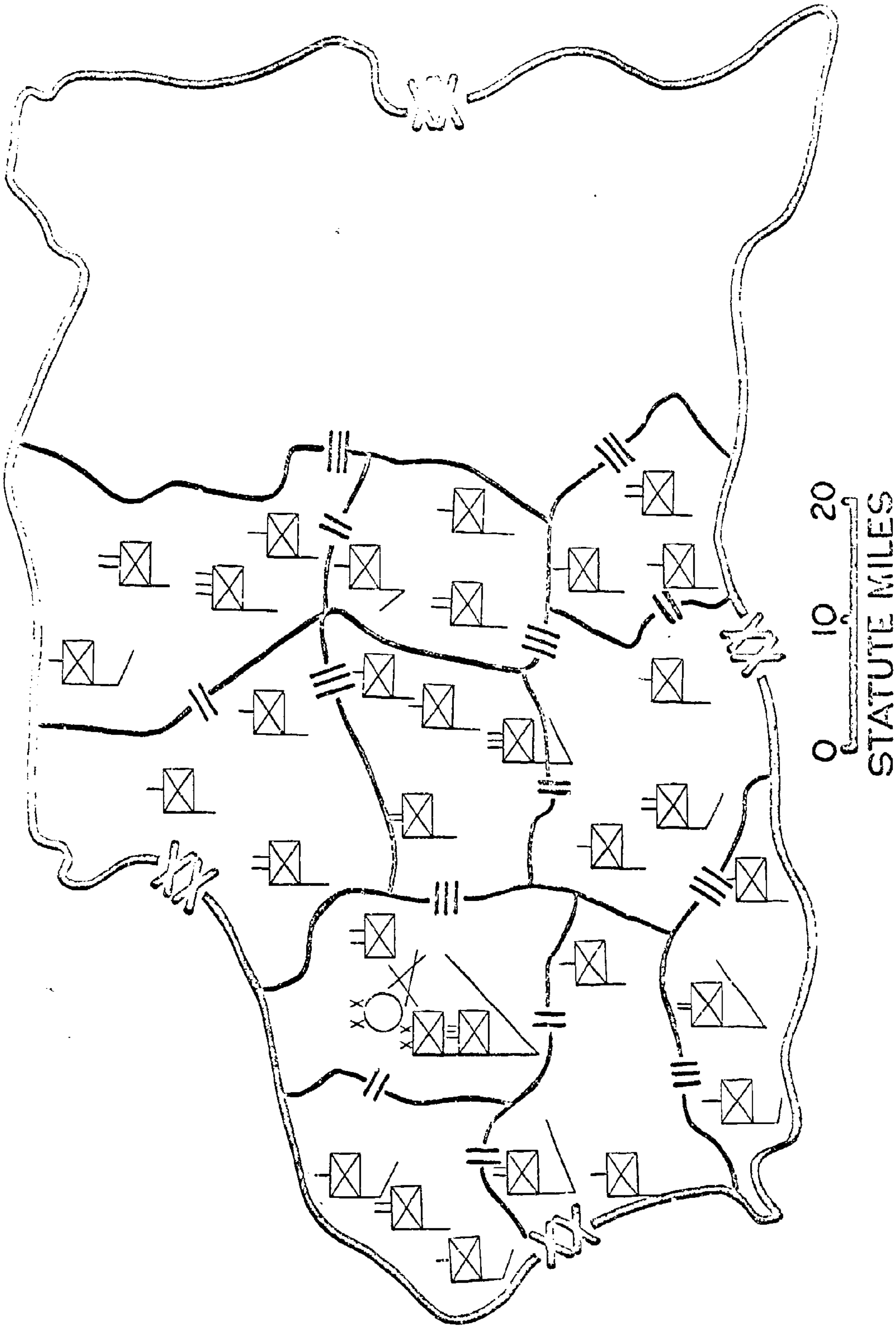

EXHIBIT 3 - DIVISION DEPLOYMENT

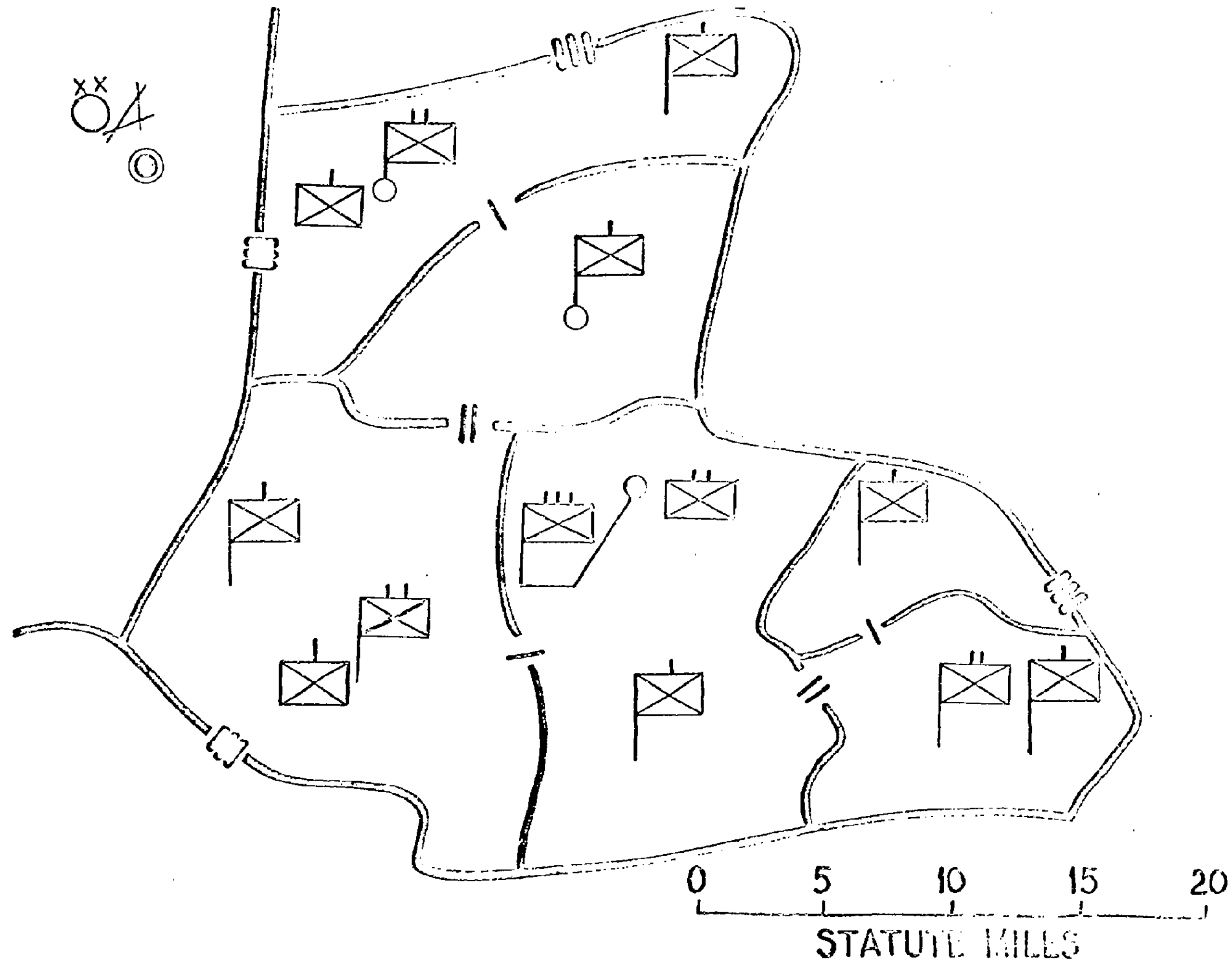

EXHIBIT 4 - TYPICAL REGIMENTAL DEPLOYMENT

guns, which are not considered a significant threat to aircraft flying at altitudes above 1,500 feet.

Eight type operations have been selected as representing the most likely areas of flex-wing utility in the military situation just described.

- o Tactical movement of reaction forces
- o Routine aerial surveillance
- o Routine resupply of combat bases
- o Temporary resupply of large reaction forces
- o Resupply of long range patrols
- o Command, staff, and courier travel
- o Aerial adjustment of artillery fire
- o Column control and route reconnaissance

These roles are described below in a series of special situations, each of which defines the tactical setting and nature of the requirement, the payload to be carried, and the distance or distances of interest.

1. First Special Situation

The situation requires rapid movement of a reaction force to reinforce an isolated garrison or engage a group of insurgents.

a. Case 1

Requirement: Move 10 men from a regimental to a battalion combat base, from a regimental to a company combat base, or from a battalion combat base to a company combat base.

Payload: 1,800 lbs.[1]

Distance-Frequency Table:[2]

Miles	f
0-5	6
6-10	19
11-15	14
16-20	4
21-25	4

[1] All calculations assume the weight of one man to be 180 pounds.

[2] Frequency refers throughout to the number of times the distance occurs in the geometry of the model province.

b. Case 2

Requirement: Move 100 men from a battalion combat base to a company combat base.

Payload: 18,000 lbs.

Distance-Frequency Table:

Miles	f
0-5	4
6-10	13
11-15	3

c. Case 3

Requirement: Move 350 men from a regimental combat base to a battalion or company combat base.

Payload: 63,000 lbs.

Distance-Frequency Table:

Miles	f
0-5	2
6-10	6
11-15	11
16-20	4
21-25	4

2. Second Special Situation

Requirement: The situation requires daily aerial surveillance of each battalion sector. Each flight will originate at the battalion combat base and fly a continuous surveillance pattern over half of the battalion sector. The surveillance pattern consists of a series of parallel flight paths spaced one mile apart. At the conclusion of the pattern the aircraft returns to the battalion combat base. One observer and a radio are required in addition to the pilot.

Payload: 360 lbs.

Distance-Frequency Table:

Miles	f
91-110	2
111-130	0
131-150	4
151-170	2
171-190	0
191-210	2

3. Third Special Situation

The situation requires that all deployed battalions and companies be resupplied from the regimental combat base by air at 5-day intervals.

a. Case 1

Requirement: Resupply deployed rifle companies.

Payload: 5,300 lbs.

Distance-Frequency Table:

Miles	f
0-5	1
6-10	5
11-15	8
16-20	2
21-25	2

b. Case 2

Requirement: Resupply battalion headquarters and headquarters companies.

Payload: 14,000 lbs.

Distance-Frequency Table:

Miles	f
0-5	1
6-10	1
11-15	3
16-20	2
21-25	2

4. Fourth Special Situation

Requirement: A regimental reaction force of 350 men has been committed to action in the vicinity of a battalion combat base or a company combat base. One day's requirement for Class I and Class V supply is to be delivered to them by air from division supply points.

Payload: 8,300 lbs.

Distance-Frequency Table:

Miles	f
0-5	1
6-10	3
11-15	4
16-20	6
21-25	4
26-30	4
31-35	6
36-40	2

5. Fifth Special Situation

Requirement: A rifle platoon on long-range patrol is to receive 5 days of supply of combat essentials by air. The point of origin is the division supply point.

Payload: 980 lbs.

Nominal Distance: 65 miles

6. Sixth Special Situation

Requirement: The situation requires that commanders, staff officers, liaison personnel, and couriers travel by air between command posts on a regular and frequent basis. Each mission involves from one to five passengers.

Payload:

Case 1	180 lbs.
Case 2	360 lbs.
Case 3	540 lbs.
Case 4	900 lbs.

Distance-Frequency Table: (Applicable to all cases)

Miles	f
0-5	5
6-10	14
11-15	6
16-20	3
21-25	3
26-30	0
31-35	1

7. Seventh Special Situation

Requirement: Direct support artillery will participate in a "search and clear" operation centered on a company combat base. An aerial observer operating from the nearest battalion combat base will remain airborne in the target area throughout the operation.

Payload: 360 lbs.

Distance-Frequency Table:

Miles	f
0-5	4
6-10	13
11-15	3

8. Eighth Special Situation

Requirement: An artillery battalion is to be shifted from one regimental sector to another. The battalion will make a motor march of 50 miles at an average speed of 20 miles per hour. The time length of the column is 0.1 hours. One or more aircraft will remain on station over the column to assist in column control, route reconnaissance, and security.

Payload: 360 lbs.

IV. DATA DETERMINATION

A. Flex-Wing and Competitive Systems

1. Conventional Aircraft

At the beginning of this study a search was made through the inventory of Army and Air Force aircraft and a selection was made to include all those with which flex-wing aircraft might be competitive or which might be involved in the comparisons necessary to evaluate flex-wing gliders. This search produced a list of seven fixed-wing vehicles and four helicopters. The fixed-wing vehicles were the U-10A Super Courier, the U-1A Otter, the CV-2B Caribou, and the C-119, C-123, and C-130 Air Force cargo types; and the four helicopters were the H-23D, UH-1D, H-34A, and CH-47A. A fifth helicopter type, the LOH-5A, was included in the list since it is likely to be in the Army aircraft inventory in the near future.

As the study proceeded, emphasizing support of indigenous forces, and as the aircraft requirements of these forces were defined, it became apparent that only the smaller, cheaper systems would be of interest and most of the types initially listed were ruled out of the evaluations. The final selection consisted of two fixed-wing and two rotary-wing aircraft, the U-6A and U-1A, and the LOH-5A and UH-1D, respectively.

The U-6A, U-1A, and UH-1D have been in the inventory for some time. Technical data concerning them are plentiful and their operational histories are amply documented. The LOH-5A offered an especially attractive comparison because of its small size. Although operational data concerning it do not exist and were estimated as required, technical data were readily available as a result of the PRC analyses.

2. Powered Flex-Wing Aircraft

The features that distinguish flex-wing aircraft are simplicity of construction--tension membrane wing, open cockpit, flat-bed cargo deck; simplicity of control--pitch and roll only; and a minimum of engine and flight instrumentation. If these features provide economy and flexibility, they are also responsible for performance characteristics which are quite unlike those of aerodynamically clean aircraft.

Up to the present, only one powered flex-wing vehicle has been built and flown--the Ryan XV-8A Fleep (Exhibit 5). This aircraft has a typical Rogallo wing fabricated from polyester-coated Dacron cloth and continuously attached along the leading edges and keel structures; a truss-like spreader bar cross member, which supports the keel and leading edges, resists inward and upward forces resulting from membrane tension, and provides a path for the transmission of air loads to the wing support structure. The wing is supported from an A-frame and aft tripod structure, which is attached to the vehicle cargo deck. A tricycle landing gear, with steerable nose wheel, direct-drive reciprocating engine with fixed pitch propeller, and minimum engine and flight controls completes the picture of an unsophisticated utility vehicle.

It is well known that the Ryan Fleep does not represent an optimized flex-wing utility aircraft and that a sound "go-around" would lead to an aerodynamically--as well as structurally--improved configuration. A modified Fleep is being planned and its features are used in the study to characterize flex-wing aircraft. The modifications are simple changes of some of the design features of the original vehicle, such as moving the butterfly tail from the cargo deck to the keel at the trailing edge of the wing. The expected improvements are modest; as examples, L/D is increased to 4.5 from 3.9, and fuel flow at maximum range speed is decreased to 64 from 66.1 pounds per hour.

Extrapolating from the Fleep is possible and a family of powered flex wings can be envisioned. For this study, two members of this family--in addition to the Fleep--were considered. One was "designed" to carry a 2,000-pound payload; the other is capable of carrying 3,000 useful pounds. As the evaluations turned out, the smallest flex wing was rarely penalized because of its size, and the basic evaluations were conducted with it as a basis.

Although all members of the family possess similar performance characteristics and are subject to the same design constraints, certain features vary as the aircraft increases in size. Increase in gross weight requires larger engines, necessitating larger propeller diameters to

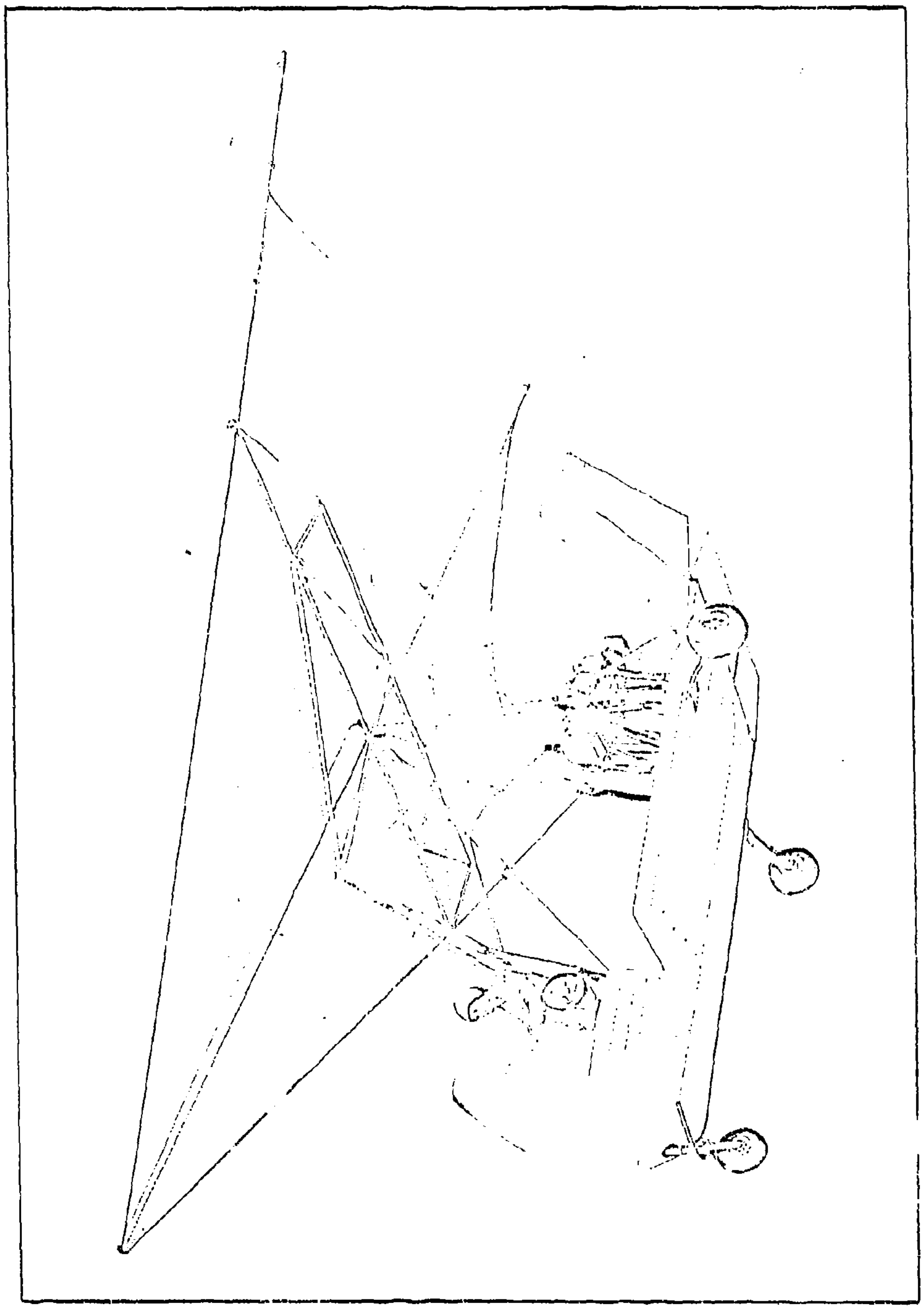

EXHIBIT 5 - POWERED FLEX-WING VEHICLE (RYAN FLEEP)

absorb the power. If the pusher engine configuration is maintained, propeller clearance requires moving the wing a greater distance above the cargo deck, increasing the parasite drag and lowering the effective L/D below the design value of 4.5. Therefore, the larger vehicles are of a tractor configuration. Preliminary weight and balance studies were made of these configurations. They were sized about available direct-drive air-cooled engines, selected to conform with a specified 12-lb/h.p. power loading requirement.

Generally, the family of powered flex-wing utility vehicles may be represented by a straight line that denotes the variations of gross weight with payload, and by fixed values for all performance characteristics including takeoff and landing runs. As aircraft gross weight approaches 20,000 pounds, improved engine performance is required. This implies supercharging, gear reduction, and controllable pitch propellers. Thus, the larger members of the flex-wing family will by no means be as simple as their smaller counterparts.

3. Towed Flex-Wing Gliders

The towed flex-wing glider is similar in construction to the powered version described above. The Ryan configuration (Exhibit 6) possesses a Delta wing of polyester-coated Dacron, attached to a rigid cross member which maintains the sweepback angle of the leading edges at 50 degrees and transmits wing loads through the aft tripod to the cargo deck structure. Side loads are also transmitted to the cargo deck through a sliding tube in the apex fitting of the forward A-frame support structure. Changes in wing incidence from the takeoff to the cruise or towed flight mode are effected through an electrical linear actuator that varies the distance between the apex fitting on the forward A-frame and the wing. A single metal fin attached to the underside of the keel provides directional stability and yaw damping.

A tow bridle consisting of four lengths of standard aircraft steel cable terminates at the tow-bridle spreader bar; the tow-bridle spreader bar has provisions for attachment to the main tow cable. When under load, the bridle generates corrective moments around the roll, yaw, and pitch

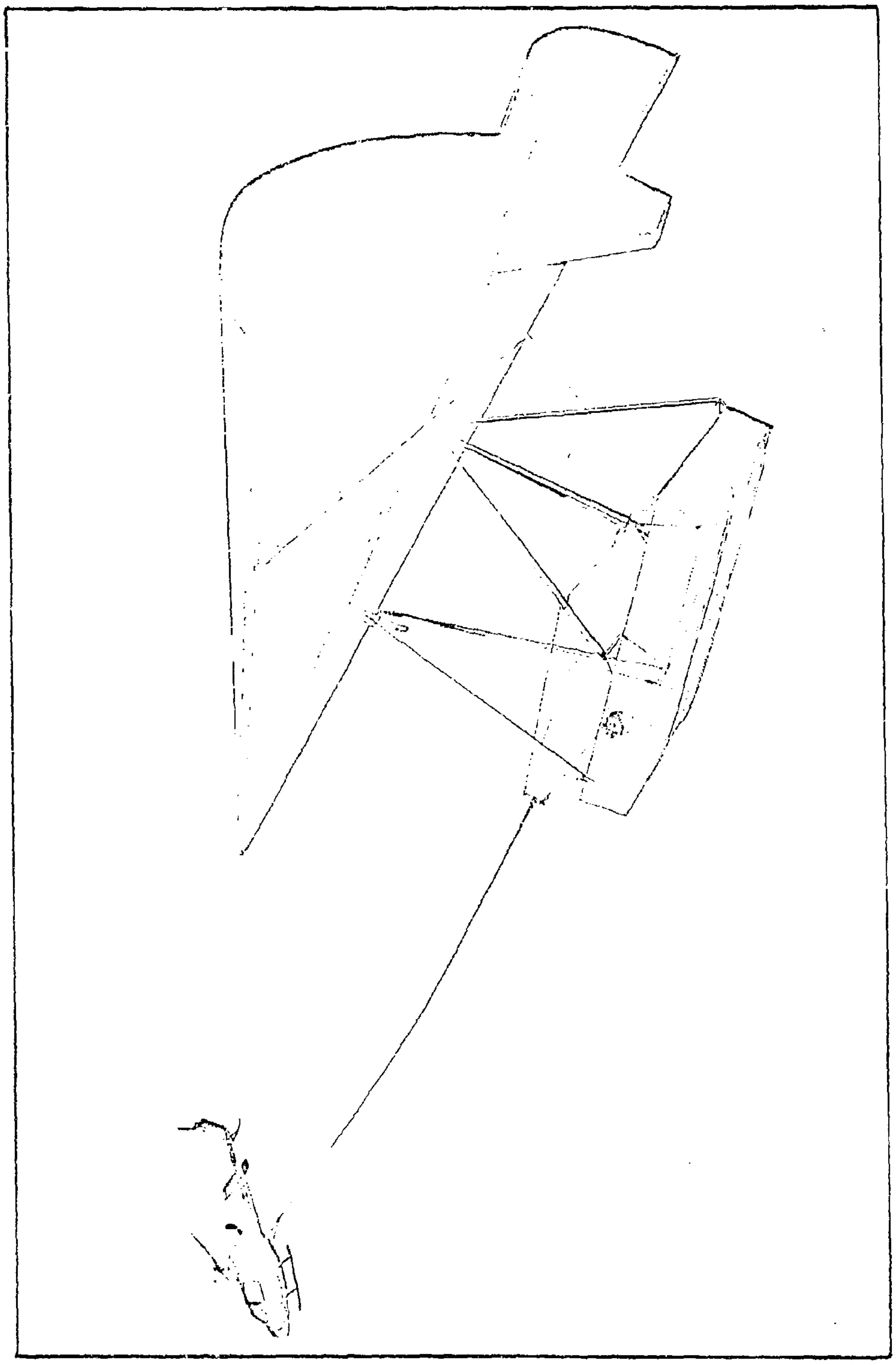

EXHIBIT 6 - TOWED FLEX-WING GLIDER

axes to damp out tow-cable oscillation and to reduce differential attitude changes between the towed glider and towing aircraft. There are no requirements for roll or pitch inputs to the glider after takeoff or while in the cruise or tow mode.

The cargo glider can be towed to a landing, in which case no control inputs are required, or it may be cut free from its towing aircraft at altitude for controlled or homing free-flight to a designated area. Automatic flare is optional and is initiated when a lanyard, suspended from the cargo deck, strikes the ground.

The several aircraft considered in the study differ with respect to their glider-hauling ability. In general this is true and the glider concept must be thought of as a family for the purpose of evaluation. Although only two members of this family, a 2,000-pound-payload version and one of 8,000 pounds, are involved in the comparisons, the family is implicit in their specifications.

B. Performance Data

1. General

Guidelines for the selection of performance characteristics were obtained from concurrent studies of the operational environments appropriate to counterinsurgency operations and of the missions for which aircraft would be required. The parameters chosen include not only those involved in the actual numerical analyses performed but others important to any evaluation of flex-wing aircraft. For example, the hover ability of a helicopter is hardly included in any of the cost-effectiveness models. Yet for those missions requiring this ability, the helicopter is unique and no basis exists for comparing it with the flex-wing aircraft.

Basic data for the aircraft and flex-wing studied are presented in Exhibit 7. These and the performance data to be discussed in the following subsections were obtained or derived from standard manuals and reference sources.

For the U-6A, Janes' All the World's Aircraft was a source of most data including those on takeoff and landing runs. Velocity data were

EXHIBIT 7 - BASIC CONVENTIONAL AND FLEX-WING AIRCRAFT DATA

Conventional Aircraft	Power Plant	Dimensions (ft) Span	Wing Area (ft^2)	Length	Cargo (ft^3)	Door	Rotor (dia.)	Weight (lbs) Operating	Empty	Useful Load	Gross
Beaver, U-6A Utility Aircraft	P and W R-985 Wasp Junior 2-bladed controllable pitch propeller: 8-1/2-ft. diameter Normal rating: 450 H. P. Fuel cap: 830 lbs.	48	250	30	134	3-1/2 x 3-1/2		3,200	3,000	1,900	5,100
Otter, U-1A Utility Aircraft	P and W R-1340-S1H1-G Radial Engine or - S3H1-G 3-bladed controllable pitch propeller: 10 ft., 10 in. diameter Normal rating: 600 H. P. Fuel cap: 1,280 lbs.	58	375	42	5-ft. H x 5-ft. W x 12-1/2-ft. L	4 x 4		5,100	4,900	2,900	8,000
Hiller LOH-5A	Allison: T63-A-5 Shaft Turbine Normal rating: 212 S. H. P. Fuel cap: 440 lbs.			29.4	75 (approx.)		35	1,570	1,345	840 1,430	2,410 3,000
Bell UH-1D	Lycoming T53-L-11 Shaft turbine: 1,100 S. H. P. Norm. rating: 900 S. H. P. Fuel cap: 1,430 lbs.			39.5	4-1/2-ft. H x 8-ft. W x 7-1/2-ft. L	6-ft. W x 4-ft. H	48	5,070	4,870	4,430	9,500
Powered Flex-Wing Aircraft											
Powered Flex-Wing (Ryan-Fleep)	Continental 10-360-A 4-cyl., direct drive, air-cooled engine Normal rating: 180 H. P. Weight: 375 lbs. incl. 7-ft. fixed pitch propeller Fuel cap: 150 lbs.	33.4	450	20	4-ft. H x 5-ft. W x 6.5-ft. L			1,350	1,115	1,150	2,500
Powered Flex-Wing (Utility Vehicle)	Lycoming 10-720-A1A 8-cyl., direct drive, air-cooled reciprocating Normal rating: 380 H. P. Weight: 700 lbs. incl. 8-1/2-ft. fixed pitch propeller Fuel cap: 250 lbs.	44	800	41	4-ft. H x 5-ft. W x 10-ft. L			2,250	2,000	2,250	4,450
Powered Flex-Wing (Utility Vehicle)	P and W R-1340-S1H1-G, or the British Alvis Leonides 530 Series Radial Engine 3-bladed control pitch propeller: 10-ft. diameter Normal rating: 550 H. P. Engine plus propeller weight: 1,000 lbs. Fuel cap: 350 lbs.	52	1,200	50	4-ft. H x 5-ft. W x 15-ft. L			3,300	3,100	3,350	6,650

derived from the U-6A Operator's Manual, TM 55-1510-203-10. Derivations were based on speed-load information obtained from column I of this manual.

Janes and the U-1A Operator's Manual were used in the same way for calculations involving the Otter except that data on takeoff and landing runs were not available in Janes and were obtained from the manual.

Data concerning the LOH-5A are from Engineering Report Number 60-92, a Hiller Aircraft Company document.

Data concerning the UH-1D are from Janes and from Bell Helicopter Company letter documents.

All flex-wing data of both the powered and towed versions were obtained from Ryan Aeronautical Company documents or from communications with Ryan personnel.

2. Conventional Aircraft

The performance characteristics of the aircraft involved in this study are summarized in Exhibit 8. All were calculated assuming sea-level standard conditions. Operations at altitude or under special conditions of temperature and humidity would vary performance data. Generally, the resultant changes vary almost directly with changes in conditions and would not affect comparisons. For all aircraft considered, operations should be limited to altitudes on the order of 7,500 feet, but this was not considered to be a serious restriction in the environments studied.

V is the aircraft velocity when operated at maximum continuous rated power. Generally, this velocity was used in the evaluations because it is the most economical one at which to operate if aircraft costs are apportioned linearly over a lifetime consisting of a fixed number of flying hours. Engine manufacturers, when questioned, insisted that flying at reduced power would not increase engine life and that fuel expenditures invariably represent a small portion of hourly operating costs. Velocity, of course, varies with gross weight and the value tabled is a compromise selected from a graph of this variation. Use of this single value in calculations probably does not introduce errors exceeding a few percent.

EXHIBIT 8 - CONVENTIONAL AIRCRAFT PERFORMANCE CHARACTERISTICS

	V (knots)	f (lbs/hr)	$f_{(end)}$ (lbs/hr)	U (lbs)	L (lbs)	m (men)	ℓ (litters)	T.O. (ft)	$T.O._{50}$ (ft)	L.R. (ft)	$L.R._{50}$ (ft)
U-6A	132	230	100	1,900	830	6	2	815	1,250	590	1,250
U-1A	128	400	150	2,900	1,280	10	6	1,045	1,605	565	1,225
LOH-5A	112	165	145	1,430	440	3	1	--	150/200	--	100/150
UH-1D	116	590	515	4,430	1,430	12	6	--	200/300	--	100/150

EXHIBIT 9 - POWERED FLEX-WING AIRCRAFT PERFORMANCE CHARACTERISTICS

Payload	V (knots)	f (lbs/hr)	$f_{(end)}$ (lbs/hr)	U (lbs)	L (lbs)	m (men)	ℓ (litters)	$T.O._{50}$ (ft)	$L.R._{50}$ (ft)
1,000 Pounds (Ryan Fleep)	65	75	64	1,150	150	6	4	770	460
2,000 Pounds	65	150	115	2,250	250	10	6	770	460
3,000 Pounds	65	265	185	3,350	350	16	10	770	460

f is the hourly fuel flow at maximum continuous power.

f (endurance) is the hourly fuel flow corresponding to velocity for maximum endurance. These values were used to estimate the feasibility of missions involving loiter, such as artillery adjustment and column control, but did not enter into any calculations. This procedure introduces only neglible errors into the hourly costs associated with these missions.

U is the useful load that can be carried by an aircraft. It does not include the weight of a pilot or of the empty aircraft, but it must be decreased by the fuel carried in order to calculate payload.

L is the weight of fuel that can be carried in the aircraft standard tanks. Except as noted later when glider characteristics are discussed, it did not enter the evaluations and need not be considered as having relevance to the results.

m is the personnel carrying capability of an aircraft, excluding pilot. These values were not computed for the study and it is conceivable that they would be larger for indigenous troops of smaller physical stature than Americans in general.

ℓ is the litter-carrying capability of an aircraft. Statements similar to those made immediately above would also be appropriate here.

T.O. and L.R. are the ground distances required for takeoff and landing, respectively. They apply to normal gross weight conditions and would vary somewhat with any changes in these conditions.

$T.O._{50}$ and $L.R._{50}$ are the total distances required to clear a 50-foot obstacle on takeoff and landing respectively. They also apply to normal gross weight conditions and are sensitive to changes in these.

3. Powered Flex-Wing Aircraft

The performance characteristics of the three powered flex-wing aircraft studied are summarized in Exhibit 9.

The flex-wing vehicles evaluated are, like the Fleep, assumed to have enough control on the ground to take off in a 90-degree cross wind of 15 knots. In flight, the two-axis control system provides adequate maneuverability at 65 knots without exceeding the limit load factor of 2.5. The flat lift-curve slope of the Delta wing configuration and the low operating speeds of the aircraft mitigate the possibility of abrupt large changes in C_L when encountering vertical gusts or changes in elevator angles. The prospect of exceeding the limit load factor because of gust or maneuver is therefore slight.

The light wing loading and low operating speed of flex-wing vehicles make them responsive to even the lightest of gust conditions. Thus, flying at low altitudes, as would normally be the case, could be an uncomfortable experience--a good reason for planning flight durations not to exceed, say, 2 hours.

4. Towed Flex-Wing Gliders

Several basic design parameters are held constant for all gliders studied. In these vehicles L/D = 3.5, wing loading = 6 pounds per ft^2, wing leading edges are swept back 50 degrees, and the center of gravity of the cargo is below the wing, a distance equal to 43 percent of the keel length. Actually, this latter statement depends on cargo distribution as the glide ratio depends on the shape and size of the cargo being carried. Empty weight is treated as a linear function of payload and the two points studied--2,000- and 8,000-pound payloads--define this relationship.

The inherent dynamic stability of the towed flex-wing glider has been demonstrated successfully many times in flight tests conducted jointly by Ryan Aeronautical Company and the Army Transportation Research Command at the Yuma Proving Grounds, Yuma, Arizona. Although these tests have involved only helicopters, this study assumes that fixed-wing towing would be similarly feasible. Towing a flex-wing glider, however, is not without its hazards and penalties. Some payload capability--internal to the towing vehicle--must be sacrificed to an observer who monitors takeoff, flight, and landing. Pilot and crew require intensive training before these operations can be performed with reasonable safety. Precision of operation is also a function of the skill levels of pilot and observer especially under marginal weather conditions. The glider capabilities used in this study are nominal and will be degraded by hot and humid weather and gusty air and other adverse environmental conditions.

Glider performance data are presented in Exhibit 10. These performance data are, to a large degree, a function of the nature of the towing aircraft. When towed behind a fixed-wing aircraft or helicopter, the flex-wing glider imposes an appreciable drag on the towing vehicle. This drag increment may be expressed in terms of horsepower required, as a function of the speed, in which form it is illustrated for several glider payloads in Exhibit 11. These drag effects determine the maximum payload an aircraft can tow as well as the maximum speed at which this can be done. The following paragraphs indicate how these glider characteristics and takeoff and landing runs were determined.

When towing a glider, each aircraft was assumed to fly with full fuel tanks and with an observer. Thus, the gross weight of the U-6A, for example, during towing operations was taken as 4,220 pounds and the power required to fly this configuration at various speeds is shown in Exhibit 12. Also shown in the exhibit are curves, derived from Exhibit 11, representing the power required when the Beaver is towing a 1,000-pound-payload and a 2,000-pound-payload glider. The maximum glider payload that the Beaver can carry is then set by the speed at which the haul can be performed when the aircraft is operating at maximum continuous power. For the Beaver, this maximum glider load is nearly 2,000 pounds since larger payloads would force system speed too close to the stalling speed of the aircraft. For the U-1A Otter, a similar analysis was performed, but since fundamental data were lacking in this case, they were generated using certain assumptions. A major assumption was that both Otter and Beaver would have roughly the same L/D and other aerodynamic characteristics; on these grounds a power-required curve for the Otter was constructed. Propeller efficiency and power available were then calculated from basic engine data.

Power available and required curves for helicopters normally take on a form different from that of fixed-wing aircraft. Exhibit 13

EXHIBIT 10 - TOWED FLEX-WING GLIDER PERFORMANCE CHARACTERISTICS

	G (lbs)	V_G (knots)	$T.O._{(G)}$ (ft)	$T.O._{(G)50}$ (ft)	$L.R._{(G)50}$ (ft)
U-6A	2,000	64	1,560	2,200	175
U-1A	2,000	67	1,640	2,285	175
LOH-5A	2,000	53	600	1,325	175
UH-1D	8,000	52	2,000	2,400	175

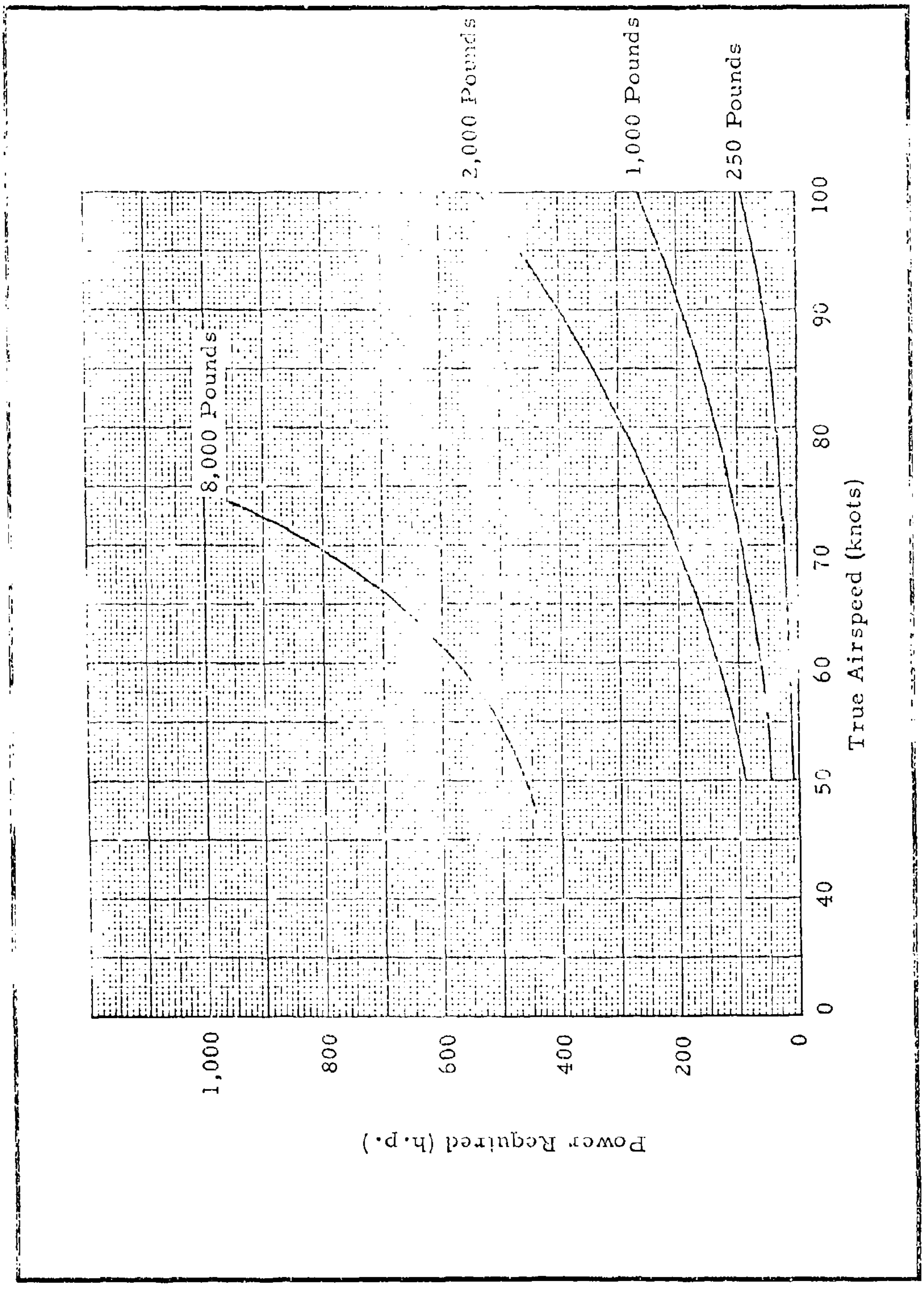

EXHIBIT 11 - HORSEPOWER REQUIRED TO TOW FLEX-WING GLIDERS

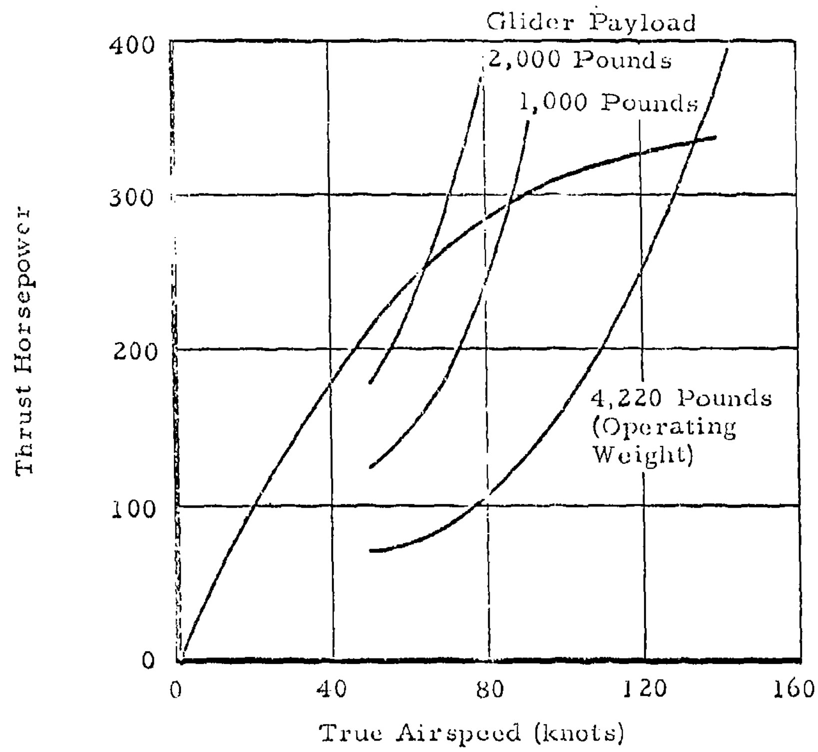

EXHIBIT 12 - U-6A--POWER REQUIRED AND AVAILABLE VERSUS TRUE AIRSPEED

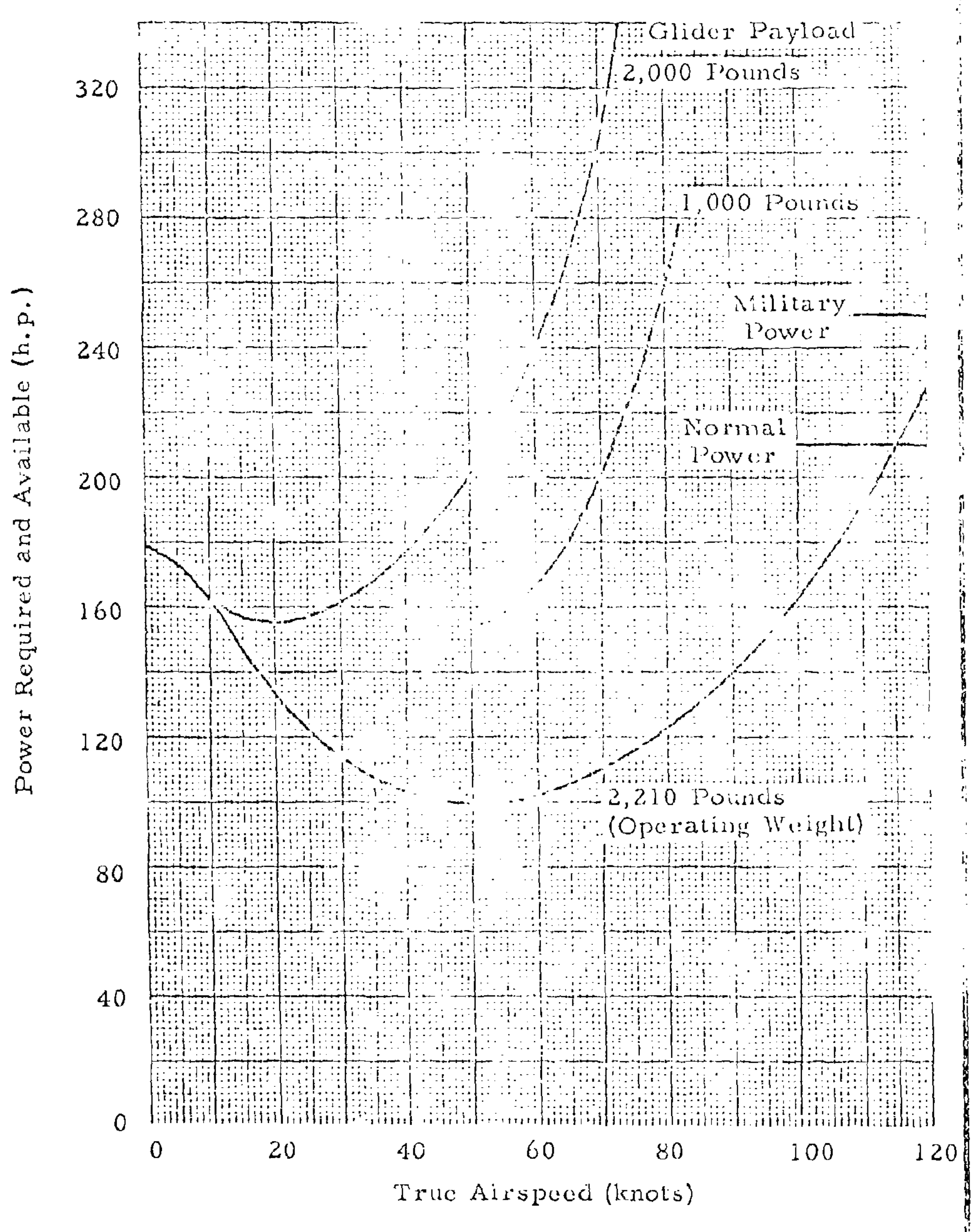

EXHIBIT 13 - LOH-5A--POWER REQUIRED AND AVAILABLE VERSUS TRUE AIRSPEED

shows this information for the LOH-5A operating at its towing weight of 2,210 pounds. Also shown in this exhibit are curves, derived from Exhibit 11, representing the power required when the LOH-5A is towing a 1,000-pound-payload and a 2,000-pound-payload glider. Similar curves were constructed for the UH-1D. Because of the low speed capabilities of helicopters, maximum glider payloads for these aircraft are governed by the stalling speed of the glider that was taken as somewhere between 50 and 55 knots.

In this manner, G , the maximum glider payload an aircraft can tow safely, and V_G , the speed at which this can be accomplished, were determined for each aircraft.

Landing the towed flex-wing glider is accomplished by cutting it loose during descent. Since the glider is on skids its unobstructed ground run is negligible. Based on a glide ratio of 3.5, landing runs over a 50-foot obstacle approximate 175 feet. If the tow-craft is to land at the objective area, the run required for the "system" is the larger of the distances required by aircraft and glider alone.

Fixed-wing system takeoff runs were computed by linear extrapolation from data provided by Ryan--in the case of the Beaver--or from basic data on the aircraft alone--in the case of the Otter. The Ryan data covered takeoff of the Beaver towing a 1,000-pound-payload glider. The total weight of this system was 5,370 pounds. The total weight of a 2,000-pound-payload glider system is 6,820 pounds, which is 1.27 of the Ryan system. Takeoff runs required by the heavier system should be proportionately greater. The Beaver values for T.O. and $T.O._{50}$ shown in Exhibit 10 use these greater distances and include 400 feet for cable and the lengths of aircraft and glider.

Otter values were similarly obtained from data appropriate to the aircraft alone since no glider information was available. The values shown in Exhibit 10 are likely to be underestimates. This conclusion follows from the fact that calculations of this sort performed on the Beaver gave numbers smaller than the tabled values.

Helicopter system takeoff runs were determined by numerical integration of the equation:

$$S = \int_{0}^{V_{TO}} \frac{V}{HP_{EX}} \, d\left(\frac{MV}{2}\right)^2$$

where V = forward speed

V_{TO} = takeoff speed of the glider

HP_{EX} = excess horsepower available

M = mass of the system

Takeoff runs over a 50-foot obstacle were computed assuming constant horizontal speed during the climb. All excess horsepower is therefore available for climb. Since speed is unchanged, excess horsepower and, consequently, rate of climb are constant.

C. Cost Data

1. General

Aircraft cost analysis includes two major cost areas: procurement and operations. Procurement costs include aircraft flyaway, aircraft spares, ground support equipment, training, and transportation of aircraft and spares to their destination. Operation costs include pay and allowances, maintenance material, and POL.

Procurement costs might also include facilities but these were not considered since they would not be expected to differ much from system to system and because they must be estimated on a country basis and require fairly comprehensive information on existing facilities and national plans for aircraft use. Operating costs sometimes included in cost analyses but omitted here are attrition, maintenance of ground support equipment, annual training, and annual transportation and travel. For purposes of this study they may be regarded as insignificant.

Aircraft costs may be treated in at least two ways: total system costs for a given period or costs per operating hour. Either approach requires essentially the same data and assumptions although one is generally more appropriate to a given goal. For this study, since competitive systems are to be compared with respect to types of missions rather than a particular complex mission, hourly costs provide a particularly simple means of evaluation. Whenever mission effectiveness can be matched, merely being able to calculate operating times leads to a straightforward cost-effectiveness comparison.

No cost analysis can be accomplished without assumptions. Consequently all cost conclusions must be tentative ones until their sensitivity to these assumptions has been determined. The following assumptions underlie the data to be presented in the next three subsections. The list is not exhaustive although it covers most of the more important points and other assumptions will be explicitly stated throughout the discussion.

- For each aircraft, flyaway costs are for about 1,000 units of production.
- Each aircraft flies 500 hours per year.
- Each aircraft system is "installed" in a country about 8,300 miles from the U.S. west coast where the military pay scale is about 1/10th that of the U.S. (These conditions approximate Thailand.)
- The existing airbase and maintenance facilities of this country are adequate for any of the aircraft considered.

2. Conventional Aircraft Costs

Conventional aircraft costs are given in summarized form in Exhibit 14.

With the exception of the LOH-5A, 1964 flyaway costs (less avionics) were obtained from the Army Materiel Command. Generally, avionics for these aircraft are roughly 8 to 12 percent of flyaway costs. Such sophistication is not appropriate to the aircraft missions of interest

EXHIBIT 14 - CONVENTIONAL AIRCRAFT COSTS

	U-6A	U-1A	LOH-5A	UH-1D
Procurement[1]				
Flyaway	52.0	112.2	107.4	255.0
Spares	9.5	8.5	30.5	88.5
Ground Support Equipment	0.5	1.1	1.1	2.6
Pilot Training	4.1	4.5	2.1	2.9
Maintenance Training	1.6	2.6	4.0	4.0
Initial Transportation	1.4	2.3	0.6	2.3
Subtotal	69.1	131.2	145.7	355.3
Operations[2]				
Pilot Pay and Allowances	2.4	2.4	2.4	2.4
Maintenance Pay and Allowances	0.4	0.7	1.0	1.0
Maintenance Material	19.0	17.0	61.0	177.0
POL	5.2	9.0	3.8	11.7
Subtotal	27.0	29.1	68.2	192.1

Notes: (1) In thousands of dollars per aircraft.

(2) In dollars per flying hour; 500 flying hours per year is assumed to arrive at pilot and maintenance pay and allowances per flying hour.

to the study, which require little more than a capability to transmit and receive voice. A rough estimate of 2 percent of cost was made for avionics, and the flyaway costs shown include this increment.

The LOH flyaway cost is based on data obtained from a PRC study for the Hiller Aircraft Company. It is based on a procurement of 1,000 aircraft and includes a pro-rata share of the R and D costs which were estimated for that study.

Initial spares are usually costed at a fixed percent--often 20--of flyaway cost. For the aircraft considered here, such an approach leads to unreasonable stockpiling insofar as maintenance material costs per operating hour are a basis for judgment. Since most of these latter are based on records of military operations, it seems appropriate to regard them as realistic. Ideally, initial spares should be expected to cover some specified number of flying hours or some picked period of time. The tabled values cover 500 flying hours (one year of aircraft life) and are based on maintenance material costs.

Ground support equipment ordinarily is about 1.5 percent of flyaway cost; 1 percent is used here to provide a minimum ground support equipment complement.

Pilot training costs include instructor and student pay and allowances and POL costs for instructional hours. The calculated costs assume a crew ratio of 1.5 and an instruction ratio (instructors per pilot) of 0.25. Length of instruction (57 weeks for fixed-wing aircraft and 27 weeks for helicopters) and instructional flying hours (100) are based on courses given U.S. pilots. Instructors are considered to be senior-ranking noncommissioned officers receiving U.S. pay and allowances including travel and per diem, and students are paid 0.1 the salary of a U.S. cadet since they are members of indigenous forces. POL costs are based on aircraft performance data and a per-gallon expense of 5 cents, which is based on Air Force data and represents service-wide experience.

Maintenance training costs are similarly estimated but they consist entirely of pay and allowances. Duration of instruction is based on the length of U. S. courses. It is assumed constant (10 weeks) for all aircraft and includes training in aircraft maintenance, and repairs of propellers, instruments, electrical and fuel systems, and engines. An air instruction ratio of 0.25 is again assumed but crew ratios--estimated from Army records of maintenance labor cost per flying hour--vary from 0.47 to 1.2. The U-6A merits the smaller value, the helicopters the larger, and the U-1A with a ratio of 0.8 is in the middle. Maintenance instructors are assumed of lower rank than pilot instructors but trainees of both sorts are treated the same.

Initial transportation of aircraft, spares, and ground support equipment is assumed to be handled by MATS and is costed at MATS rates.

Pilot pay and allowances per flying hour is simply taken as 0.1 the pay of a U.S. warrant officer and apportioned over 500 hours. The area ratio, of course, is also a factor.

Maintenance pay and allowance per flying hour is assumed to be 0.1 the pay of a U.S. staff sergeant. Yearly flying hours and the crew ratios discussed under training complete the data necessary for the calculations.

Maintenance material cost per flying hour for the U-6A, U-1A, and UH-1D are taken from Army data. LOH-5A costs were estimated from a sample of seven helicopters and assumed a relationship between maintenance and flyaway costs.

Fuel costs are based on fuel flow when engines are operating at maximum continuous rated power since they are treated this way in the eff[illegible] analyses. These values are a little high as inputs to the calculation of pilot training costs and tend to exaggerate the cost differences between aircraft of the same type but of different sizes.

5. <u>Powered Fixed Wing Costs</u>

Powered fixed wing aircraft costs are summarized in Exhibit 15. These data are of the same form as those of Exhibit 14 except for the inclusion of two estimates for all material entries. Essentially,

EXHIBIT 15 - POWERED FLEX-WING COSTS

	1,000-Pound Payload		2,000-Pound Payload		3,000-Pound Payload	
	High	Low	High	Low	High	Low
Procurement(1)						
Flyaway	15.3	7.1	27.4	12.6	42.2	19.4
Spares	2.4	1.1	4.4	2.0	6.1	2.8
Ground Support Equipment	0.1	0.1	0.2	0.2	0.3	0.3
Pilot Training	1.4	1.4	1.4	1.4	1.5	1.5
Maintenance Training	0.6	0.6	0.7	0.7	0.8	0.8
Initial Transportation	0.5	0.5	1.0	1.0	1.5	1.5
Subtotal	20.3	10.8	35.1	17.9	52.4	26.3
Operations(2)						
Pilot Pay and Allowances	2.4	2.4	2.4	2.4	2.4	2.4
Maintenance Pay and Allowances	0.3	0.3	0.3	0.3	0.4	0.4
Maintenance Material	4.7	2.[illegible]	8.7	4.0	12.2	5.7
POL	1.7	1.7	3.4	3.[illegible]	5.0	5.0
Subtotal	9.1	6.[illegible]	14.8	10.1	20.[illegible]	13.5

Notes: (1) In thousands of dollars per aircraft.

(2) In dollars per flying hour; 500 flying hours per year is assumed to arrive at pilot and maintenance pay and allowances per flying hour.

this multiplicity is due to the fact that three approaches were taken to estimate flyaway cost. Since flyaway cost is so critical a cost factor and since flex-wing studies can call on no line production experiences on which to base an estimate, an attempt was made to bracket the feasible range.

The "high" estimates of flyaway cost assume an engine cost of $10.00 per horsepower and a structure (airframe, fabric, etc.) cost of $17.80 per pound. The structure cost is based on data provided by Ryan for their XV-8A Fleep extrapolated to a 1,000-unit cost.

The "low" estimates of flyaway costs are based on conversation with manufacturers and PRC's engineering judgment. Engines are costed at $8.00 per horsepower and structure at $7.50 per pound. Because of the long production history of the engine types considered for the flex wings, it is not likely that even quantity purchases would result in significant cost savings. Eight dollars per horsepower is probably a near-minimum cost. Similarly, but not on such good grounds, it is felt that $7.50 per pound represents a minimum cost for aircraft built and assembled in the United States.

But even this "low" estimate may be too high if conditions are changed. Since flex-wing aircraft are of such simple structure, lower levels of technological skills using cheaper tools could undoubtedly build them. While engines would probably still have to be imported, in-country construction and assembly would unquestionably lead to an even lower than "low" cost estimate. And even if complete in-country fabrication is not feasible, the cost picture might be significantly altered if the purchase of kits were considered a possibility.

The flyaway costs exhibited, both sets, include 2 percent for avionics for the reasons given previously (subsection C.2). Generally, other powered flex-wing costs follow the logic of that subsection but there are some exceptions.

A 20-week pilot training course requiring 50 flying hours is considered sufficient for flex-wing pilots. It is also considered more or less necessary. While it may be true that a truck driver could solo a flex-wing following a few hours of instruction, it is not likely that he would then be as qualified to fly it as would, for example, a U-6A pilot. The ability to take off and land in an aircraft without catastrophe falls short of pilot status and the uses of powered flex wings visualized in this study entrust many lives to the pilot on many occasions.

The calculation of maintenance training costs differs from the previous calculation only in the length of the course and the maintenance crew ratios. Maintenance training comparable to that given for fixed-wing aircraft was assumed but not all courses were considered to be necessary or to be as detailed. Training on instruments and electrical systems, for example, was assumed half as long as for the U-6A; propeller training is unnecessary since those of the flex wings are of fixed pitch. A total course length of 52 weeks was arrived at through this reasoning.

Maintenance crew ratios are also based on comparisons between flex-wing and fixed-wing aircraft. The largest payload version was considered comparable to the U-6A, the smaller ones less complicated. Assumed crew ratios are 0.47, 0.40, and 0.33, respectively.

Pilot pay and allowances and maintenance pay and allowances parallel the calculations for conventional aircraft. Pilot pay calculations are identical and maintenance pay calculations differ only because of crew ratio.

Maintenance material costs are based on the several assumptions that engines will be overhauled and fabric replaced every 900 operating hours. "Low" cost estimates assumed $300, $450, and $600 for engine parts, and $675, $1,350, and $1,950 for fabric for the three flex-wing sizes. "High" cost estimates are obtained from these by scaling in proportion to flyaway costs.

4. Towed Flex-Wing Glider Costs

Towed flex-wing glider costs are summarized in Exhibit 16. Except for obviously noncomparable items, calculations were similar to those appropriate to the powered versions.

EXHIBIT 16 - TOWED FLEX-WING GLIDER COSTS

	2,000-Pound Payload		8,000-Pound Payload	
	High	Low	High	Low
Procurement[1]				
Flyaway	12.2	7.2	21.2	14.6
Spares	0.8	0.4	1.6	1.2
Ground Support Equipment	Not Applicable			
Pilot Training	0.1	0.1	0.1	0.1
Maintenance Training	Insignificant			
Initial Transportation	0.3	0.3	0.8	[illegible]
Subtotal	13.4	8.0	23.7	[illegible]
Operations[2]				
Pilot Pay and Allowances	Insignificant			
Maintenance Pay and Allowances	0.1	0.1	0.1	[illegible]
Maintenance Material	1.5	0.9	3.3	[illegible]
POL	Not Applicable			
Subtotal	1.6	1.0	3.4	2.4

Notes: (1) In thousands of dollars per aircraft.

(2) In dollars per flying hour; 500 flying hours per year is assumed to arrive at pilot and maintenance pay and allowances per flying hour.

"High" flyaway cost is based on the $17.80 per pound structural cost used earlier but it includes as well Ryan's estimate of the cost of a tow kit. The "low" cost uses $7.50 per pound and this same tow kit cost since no basis existed for another estimate. Although the tow-kit cost varies from one two vehicle to another, a single cost is used since the variations are insignificant.

The tow kits are, of course, not really glider parts. They are costed in this fashion for convenience since the analysis must reflect the fact that, if they are bought, they are properly chargeable against the system they make possible. In the cost-effectiveness analyses, glider costs never enter alone and this means of costing gives correct results for each glider system. When the tow-craft operates alone, however, it is treated as if it were unmodified.

For the same reason, the additional training a pilot needs to be able to tow a glider is charged to the flex wing even though the pilot is not associated with the glider alone. Similarly, the costs of training an observer and his pay and allowances are glider costs even though the observer rides in the tow vehicle. These costs appeared insignificant and do not show in the tabled data.

In general, costs not shown in Exhibit 16 were insignificant when calculated or are not applicable in the case of the towed flex-wing glider. Those costs which are exhibited were calculated using methods described in subsection C.3. In particular, the "low" values for maintenance material assumed $384, $1,050, and $2,170 for fabric, proportional to wing area, and the "high" values were obtained by scaling in accordance with flyaway cost.

5. Cost Ratios

The cost-effectiveness analyses to follow use a ratio of system costs for comparison. All the models require these costs to be expressed in dollars per operating hour. To accomplish this from the cost data developed so far, an assumption of aircraft life or of total flying hours must be made. Hourly operating costs may then be calculated by amortizing procurement costs and adding the tabled operation costs. If, for example, 10 years of operation is assumed, procurement costs would be amortized over 5,000 flying hours and added to operations costs, which are already expressed in dollars per flying hour.

It is usual to treat military systems as if they had 5-year lives and to calculate hourly costs on this basis. In these situations, 300 flying hours are considered as the yearly average and the total useful hours that result are relatively small. In this study, it has been assumed that indigenous forces would "overwork" their aircraft and fly them 500 hours each year. It would also appear reasonable that these aircraft would not so rapidly become "obsolete" if money to replace them was scarce. Thus, 5,000 hours seems a sensible basis to use for the calculation of hourly costs.

In Exhibit 17, a number of cost ratios are tabulated. Each is a candidate for use in a particular cost-effectiveness comparison and it is apparent that the choice of which to use might influence the ultimate decision considerably. Yet this is true only insofar as the "high" and "low" flex-wing cost estimates are involved. As far as assumed life goes, the ratios are quite insensitive.

Other calculations were performed to investigate ratio sensitivity to other assumptions and the results were generally unexciting. If the indigenous pay factor is increased from 0.1 to 0.2 (which approximates South Vietnam), for example, no ratio changes more than 5 percent. This is not too surprising since personnel costs are small contributors to total costs in both cases.

Generally, it would appear that as long as underdeveloped countries and indigenous personnel are involved, cost ratios will depend heavily on flyaway, spares, and maintenance material and that these costs are really the only one worth considering.

Thus, insofar as the flex-wing "high" and "low" cost estimates are good bracketing numbers, the cost ratios in Exhibit 17 can be used to establish the range in which the study should be interested.[1] If this

[1] Although flex-wing and fixed-wing configurations can be expected to last at least 5,000 operating hours, the same is not true for helicopters. Engine manufacturers "de-rate" their engines if they are to be used in helicopters and (continued at the bottom of page 54).

EXHIBIT 17 - COST RATIOS: CONVENTIONAL AIRCRAFT VERSUS 1,000-POUND-PAYLOAD POWERED FLEX-WING AIRCRAFT

Conventional Aircraft	Assumed Life			
	2,500 Hours		5,000 Hours	
	"High" Cost	"Low" Cost	"High" Cost	"Low" Cost
U-6A	3.2	5.0	3.1	4.6
U-1A	4.7	7.5	4.2	6.3
LOH-5A	7.4	11.6	7.4	11.1
UH-1D	19.4	30.7	19.9	29.9

range is too great, it will not be narrowed by changes in estimating techniques unless these result in better flex-wing values. For the present, there is no hope this can be done.

Exhibit 18 summarizes the minimum and maximum cost ratios that will be used in the next section. Although the range of flex-wing estimates is confounded with estimated life, it is apparent that there is little interaction. Almost invariably the minimum cost ratio corresponds to a 5,000-hour life and a "high" cost estimate, and the maximum cost ratio to the short life and "low" cost.

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[1] (Continued from page 52) the operating life of these aircraft is variously estimated at between 1/3 and 1/2 the operating life of "similar" fixed-wing airplanes. Perhaps helicopter life should be considered as shorter for comparisons. The question is thorny and need not be answered here. This is especially true since most of the missions analyzed herein do not call for, or reward, the helicopters' unique capabilities.

EXHIBIT 18 - MINIMUM AND MAXIMUM COST RATIOS

Comparison	Cost Ratios Min.	Max.
U-6A Versus 1,000-Pound-Payload Powered Glider	3.10	5.00
U-1A Versus 1,000-Pound-Payload Powered Glider	4.20	7.50
LOH-5A Versus 1,000-Pound-Payload Powered Glider	7.40	11.60
UH-1D Versus 1,000-Pound-Payload Powered Glider	19.40	30.70
U-6A Alone Versus 2,000-Pound Towed Glider System	0.89	0.94
U-1A Alone Versus 2,000-Pound Towed Glider System	0.92	0.96
LOH-5A Alone Versus 2,000-Pound-Payload Glider System	0.95	0.97
UH-1D Alone Versus 8,000-Pound-Payload Glider System	0.96	0.98

V. COST-EFFECTIVENESS ANALYSES

A. Methodology

The cost-effectiveness approach to system evaluation is unquestionably the most rational one. Neither performance nor cost taken alone can possibly provide a basis for choice among systems. The rational purchaser will want the most he can get for his money or the cheapest method of accomplishing his ends.

Generally the problem is complicated by the fact that neither the performance level required nor the money that can be afforded are capable of specification in advance. An ideal solution demands that system performance be expressible in terms of system cost for each system under consideration. Such expressions may be plotted as in Exhibit 19 and choices may then be readily made.

Exhibit 19 illustrates, also, a situation that sometimes arises that complicates the cost-effectiveness problem and frequently leads to unjustifiable decisions. Should performance in excess of E_1(max) be required, system 1 is obviously not competitive. Yet it is not uncommon for such a noncompetitive system to be selected on the grounds that it is the most cost effective; i. e., that it gives the most effectiveness for the dollar. Whenever both costs and performances differ among systems, selection on these grounds alone is somewhat illegitimate. The question that immediately arises concerns the "worth" of the performance difference and unless this can be established a rational choice must be withheld.

In the comparisons made in this study, this problem arose only once, in connection with the transport of rapid-reaction troops. It will be discussed when the model for this mission is described. In general, because it was reasonable to assume that slightly different mission start and complete times did not influence mission performance, cost-effectiveness comparisons were based on equal effectiveness measures and were accomplished in the following manner.

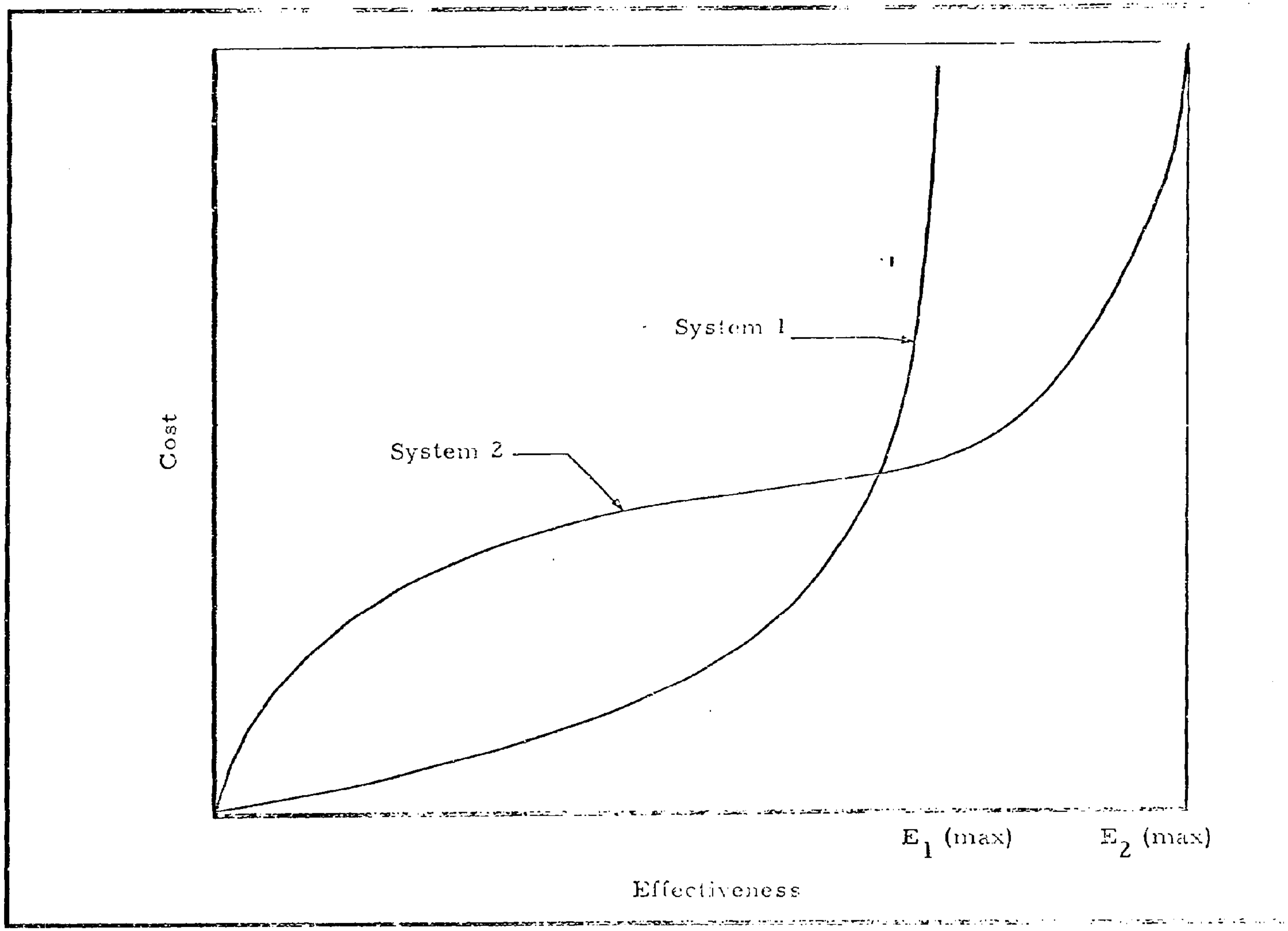

EXHIBIT 19 - SAMPLE PLOT OF COST-EFFECTIVENESS OF TWO COMPETITIVE SYSTEMS

For each mission, a generalized job was defined. This job was expressed in terms of system parameters and the expression was solved for the system operating time required. These times led to system costs, and the ratio of these costs, R, is the relative cost-effectiveness of the systems being compared. Separate comparisons were made between flex-wing and competitive systems for each mission of interest. Whenever R is greater than unity, the flex-wing is the cheapest way of accomplishing the mission. Specifically, the cost of accomplishing a mission using the flex wing is 1/R of the cost using the competitive system.

No attempt was made to combine relative performances for different missions into a single overall measure. Any such combination would depend on mission frequencies and these would vary from country to country and between levels of insurgency. Similarly, no attempt was made to synthesize an optimum mixed system since this would introduce the question of the availability of an aircraft type when the mission for which it was best arose.

Insofar as these attempts were not made and the problems of frequency and availability ignored, the analysis contains an implicit and overriding assumption. This assumption, to be truly supportable, would require an inexhaustible supply of aircraft services obtainable at any time at a fixed hourly cost. Generally, insofar as this condition is not met, the flex wings, because they are the cheapest systems, are treated unfairly. Since they are cheap, a given expenditure would purchase more of them and this flexibility in number could be translated into greater availability in time and place.

B. Models

1. General Features

Certain features are common to all of the model formulations. Others will be made explicit when the models are described and it is even possible that some of these features will be redundantly noted--in this subsection and in the model descriptions.

The models attempt, insofar as possible, to reflect the demands of the missions described in Section III. Almost without exception, these missions seem not to require speed but, rather, accomplishment. Of course it is true that speed is a factor in mobility, but most of the models assume implicitly that the slowest system performing a mission can do it as fast as it needs doing, and that additional speed does not improve performance. Speed, then, is generally of value to a system only because it reduces the operating time--and the cost--involved in the mission.

The tactical environment of Section III implied the availability of airstrips or satisfactory substitutes wherever air operations were needed. Further, the enemy's lack of weapons almost guaranteed immunity to aircraft flying above 1,500 feet. The models assume, without exception, that these conditions are met although certain improbable situations will elicit comments as they arise. The assumption of survivability obviously rules out the significance of the data for other tactical environments. The assumption of airstrip availability made it unnecessary to consider landing and takeoff characteristics of the competitive systems. The significance of these assumptions, however, is not entirely negative. In the context of the missions defined, they point up the necessity under certain conditions for air mobility, of whatever sort.

Although many missions impose requirements for aircraft time aloft that cannot be shortened by speed, the models assume that hourly costs are constant whatever the engine operating regime. This, of course, is a simplification and is not logically supportable. But since the models do not pretend to accurately reflect reality but are only aids to decision, the magnitude of error is a major question. And when total system costs are charged off to system lifetime operating hours, POL costs are truly insignificant for all but extremely long-lived systems.

Takeoff and landing times and fuel reserves are involved in every model. The former influence system operating time and therefore system cost; the latter affect maximum range and frequently payload. Values for these parameters may vary from situation to situation and country to country and a thorough study would explore all possibilities. Actually, for most practical choices, the results of the comparisons are not likely to be affected. For this reason, final calculations will be accomplished assuming that zero is an appropriate value for these parameters. Since this is true, including them in the model was in the interest of demonstrating methodology. The fact that values for these parameters are considered to be a function of the situation rather than of the aircraft involved in it should not cause any problems.

A common notational system runs through all formulations. It is summarized below to forestall the necessity for repeating it for each model. Other terms, not sufficiently general for inclusion below, will be introduced as needed.

c = cost per operating hour--conventional aircraft

c_0 = cost per operating hour--1,000-pound-payload powered flex-wing aircraft

V = maximum continuous velocity--conventional aircraft

V_0 = maximum continuous velocity--1,000-pound-payload powered flex-wing aircraft

U = useful load--conventional aircraft

U_0 = useful load--1,000-pound-payload powered flex-wing aircraft

L = tank fuel capacity (pounds)--conventional aircraft

L_0 = tank fuel capacity (pounds)--Fleep

$I[x]$ = a function equal to the value of x if x is an integer, or the next integer larger than x if x is a fraction

f = hourly fuel expenditure (pounds) at V--conventional aircraft

f_0 = hourly fuel expenditure (pounds) at V_0--Fleep

F = fuel required to complete a mission--conventional aircraft

F_0 = fuel required to complete a mission--Fleep

τ = the sum of one takeoff and one landing time

r = fuel reserve expressed in units of time at V or V_0 as appropriate

m = personnel haul capacity--conventional aircraft

m_0 = personnel haul capacity--Fleep

ℓ = litter haul capacity--conventional aircraft

ℓ_0 = litter haul capacity--Fleep

2. Powered Flex-Wing Missions

a. Basic Haul

A large share of the civic action and military missions described in Section III require the movement of men and/or materiel. In most cases, time is not a critical parameter and the job to be performed can be regarded as one of moving N men or P pounds of cargo a distance of D miles. Then, if it is assumed that the aircraft must carry all fuel for the round trip and that the available load space does not limit the cargo that may be carried,[1] the following expressions represent the relative cost-effectiveness of flex-wing aircraft in accomplishing these missions.

Cargo Haul

$$R = \left(\frac{c}{c_0}\right)\left(\frac{\frac{D}{V} + \tau}{\frac{D}{V_0} + \tau}\right)\left(\frac{I\left[\frac{P}{U - F}\right]}{I\left[\frac{P}{U_0 - F_0}\right]}\right) . \qquad (1a)$$

If large loads are to be moved,

$$R \approx \left(\frac{c}{c_0}\right)\left(\frac{\frac{D}{V} + \tau}{\frac{D}{V_0} + \tau}\right)\left[\frac{U_0 - f_0\left(2\frac{D}{V_0} + 2\tau + r\right)}{U - f\left(2\frac{D}{V} + 2\tau + r\right)}\right] , \qquad (1b)$$

which is independent of load size; and if takeoff and landing times are considered negligible and a fuel reserve is not required,

$$R \approx \left(\frac{c}{c_0}\right)\left(\frac{V_0}{V}\right)\left(\frac{U_0 - 2 f_0 \frac{D}{V_0}}{U - 2f\frac{D}{V}}\right) . \qquad (1c)$$

[1] An analysis of the densities of military supplies leads to the conclusion that all aircraft considered in this study can carry their rated loads internally except in rare instances.

Personnel Haul

$$R = \left(\frac{c}{c_0}\right)\left(\frac{\frac{D}{V} + \tau}{\frac{D}{V_0} + \tau}\right)\left(\frac{I\left[\frac{N}{m}\right]}{I\left[\frac{N}{m_0}\right]}\right) \quad . \tag{2a}$$

If many men are to be moved,

$$R \approx \left(\frac{c}{c_0}\right)\left(\frac{\frac{D}{V} + \tau}{\frac{D}{V_0} + \tau}\right)\left(\frac{m_0}{m}\right) \quad , \tag{2b}$$

which is independent of the number of men to be moved; and if takeoff and landing times are considered negligible and a fuel reserve is not required,

$$R \approx \left(\frac{c}{c_0}\right)\left(\frac{V_0}{V}\right)\left(\frac{m_0}{m}\right) \quad . \tag{2c}$$

Litter Evacuation

The models of litter evacuation are identical to those appropriate to personnel haul. Equations (2a), (2b), and (2c) need only be modified by replacing m and m_0 with ℓ and ℓ_0.

b. Rapid-Reaction Troop Movement

The job of moving troops in response to insurgent activities introduces the question of speed of response. If one system can get troops to the objective area faster than another, can this difference be evaluated in terms of dollars? Under suitable conditions, it can be and the following model attempts this. It is deficient, as will be made clear, primarily because it fails to consider the cost of the troops involved in accomplishing the mission.

Consider a case wherein the presence of insurgents is reported and a tailored force is dispatched to deal with them. Assume that the insurgents can travel at rate ρ and that they leave the objective area upon detection. Then at any given time after detection they may be anywhere in a circle of area determined by ρ and this time, and centered on the objective. It does not seem unreasonable to assert that the probability of a reaction force engaging them is proportional to the reciprocal of this area. If one system takes twice as long to respond, then it must deliver two tailored forces in order to be equally effective. Except for the cost of the excess troops, the equal effectiveness cost of the slower system is clearly twice its cost to deliver the basic force. This rapid-reaction model of relative cost-effectiveness can be expressed in the following form:

$$R = \left(\frac{c}{c_0}\right)\left(\frac{\frac{D}{V} + \tau}{\frac{D}{V_0} + \tau}\right)\left(\frac{I\left[\frac{N}{m}\right]}{I\left[\frac{N}{m_0}\right]}\right)\left[\frac{\lambda + \tau + \frac{D}{V} + \delta + \left\{ I\left[\frac{N}{m}\right] - 1\right\} \epsilon}{\lambda + \tau + \frac{D}{V_0} + \delta + \left\{ I\left[\frac{N}{m_0}\right] - 1\right\} \epsilon_0}\right]^2 \qquad (3)$$

where N = size of tailored reaction force

λ = load-up and get-ready time

δ = discharge time at objective area

and the other symbols have been defined or will be defined below.

Equation (3) can be simplified by assumptions as were Equation series (1) and (2) but the size of the reaction force will not therefore vanish from the expression. This is because of the factor ϵ, which is inserted as an attempt to reflect the capacity of helicopters for simultaneous landing in contrast to the need of fixed- and flex-wing aircraft for a takeoff and landing interval. In the calculations involving helicopters, $\epsilon = 0$. In the calculations involving fixed-wing aircraft, ϵ is assumed equal to ϵ_0 and is assigned a positive value.

c. Route Surveillance

In military route surveillance, the job to be accomplished requires the traverse of M route miles at a distance of D miles from the airstrip. If Δ represents the number of trips required to accomplish the total job, then

$$R = \left(\frac{c}{c_0}\right)\left[\frac{\frac{M}{V} + \Delta\left(2\frac{D}{V} + \tau\right)}{\frac{M}{V_0} + \Delta_0\left(2\frac{D}{V_0} + \tau\right)}\right] \quad . \tag{4a}$$

Since the useful load of an aircraft can easily be converted into fuel through the use of auxiliary tanks, all aircraft considered in this study can accomplish most route surveillance missions in one trip, and

$$R = \left(\frac{c}{c_0}\right)\left(\frac{\frac{M + 2D}{V} + \tau}{\frac{M + 2D}{V_0} + \tau}\right) \quad ; \tag{4b}$$

and if takeoff and landing times are considered negligible,

$$R \approx \left(\frac{c}{c_0}\right)\left(\frac{V_0}{V}\right) \quad , \tag{4c}$$

which is independent of the particular values of the mission parameters.

d. Telephone Line Inspection

Although the problems of military route surveillance and civic action line inspection are similar ones, the latter is inevitably complicated by the necessity for landings and takeoffs as trouble is detected. The question of whether these will be feasible for other than helicopters may well be asked. It is probable that the true answer is negative and thus the mission is not truly one on which the flex-wing aircraft can be compared. The complications are thus not worthy of attack. In the simplest situation, in which takeoff and landing times are negligible and the mission can be completed by all aircraft in one trip, the line inspection model is identical to Equation (4c), and cost-effectiveness relationships are similarly independent of mission parameter values.

e. Artillery Adjustment

For artillery adjustment, aircraft are required to remain in the vicinity of the target area for varying periods of time. If the required mission is one of H hours duration, the target area is D miles from the airstrip, and Δ represents the number of trips required to provide H airborne hours over the target, then

$$R = \left(\frac{c}{c_0}\right)\left[\frac{H + \Delta\left(2\frac{D}{V} + \tau\right)}{H + \Delta_0\left(2\frac{D}{V_0} + \tau\right)}\right] \quad . \tag{5a}$$

Since all aircraft studied can accomplish at least 5-hour missions in one trip,

$$R = \left(\frac{c}{c_0}\right)\left(\frac{H + 2\frac{D}{V} + \tau}{H + 2\frac{D}{V_0} + \tau}\right) \quad ; \tag{5b}$$

and if takeoff and landing times are considered negligible,

$$R = \left(\frac{c}{c_0}\right)\left(\frac{H + 2\frac{D}{V}}{H + 2\frac{D}{V_0}}\right) \quad . \tag{5c}$$

f. Convoy Column Control

All aircraft studied can accomplish the convoy mission described in Section III in a single trip. Whenever this is so, the relative cost-effectiveness of flex-wing aircraft controlling a convoy moving a distance of M miles at v miles per hour can be expressed as follows:

$$R = \left(\frac{c}{c_0}\right)\left[\frac{\frac{M}{v} + \frac{1}{V}(2D + M) + \tau}{\frac{M}{v} + \frac{1}{V_0}(2D + M) + \tau}\right] \quad . \tag{6a}$$

When takeoff and landing times are assumed negligible,

$$R \approx \left(\frac{c}{c_0}\right)\left[\frac{\frac{M}{v} + \frac{1}{V}(2D + M)}{\frac{M}{v} + \frac{1}{V_0}(2D + M)}\right] \quad ; \tag{6b}$$

and when D , the distance from the airstrip to the convoy start point is negligible,

$$R \approx \left(\frac{c}{c_0}\right)\left(\frac{\frac{1}{v} + \frac{1}{V}}{\frac{1}{v} + \frac{1}{V_0}}\right) \quad , \tag{6c}$$

which is independent of the route length of the convoy mission.

g. Aerial Spraying

For the large aerial spray missions indicated in Section III, all aircraft studied would need to make many trips to accomplish either mission. It is likely that missions of this magnitude would merit clearing a strip in the vicinity of the spray area at which point refueling and reloading of spray could be accomplished. Then if D and τ are considered negligible and if spray rate is a linear function of aircraft velocity, the relative cost-effectiveness of flex-wing aircraft performing aerial spray missions reduces to Equation (4c), the expression appropriate to route surveillance.

3. Towed Flex-Wing Missions

The towed flex-wing glider provides a means of increasing the single-flight payload capacity of a powered air vehicle at the expense of system speed. Furthermore, the air vehicle-glider combination inevitably requires a larger takeoff area than does the aircraft alone, although, if recovery is not a problem, the glider may be used to deliver its payload to an area in which the aircraft cannot land.

It is also true that this mode of delivery would expose the tow vehicle to the objective area for a minimum time, although the drop area is not likely to be a danger zone in tactical environments such as that described in Section III.

Such a mode of operation must create a glider recovery problem and implies cost factors not covered in this study. For this evaluation, the aircraft-glider combination will be regarded as a special-purpose system especially suited to the routine delivery of large quantities of materials.

In the following model it is assumed that gliders are recovered by the vehicle performing the loaded tow. Recovery is accomplished either by internal carry of the collapsed glider or by tow of the empty one. In either case, no velocity loss is charged to the tow vehicle during the recovery trip but the glider is "charged" for the total trip time.

The model obtained is similar to the basic haul model, Equation series (1) of this section. Time is not regarded as a critical parameter of mission performance and the job is regarded as one of moving a large payload P a distance of D miles. The cost to accomplish this task is the product of the cost per trip and the number of trips required, and the relative cost-effectiveness of the glider is plainly a function of whether or not it decreases total cost.

If an air vehicle alone is used to transport the load, it carries on each trip a payload equal to the difference between its rated useful load and the fuel required to complete a round trip.

If a glider system is used to accomplish the task the glider capacity, G , is as great as the fully fueled aircraft can handle. Then, if the haul distance is such that less than full fuel is required, the single trip payload is augmented by L - F which is assumed to be carried internally.

Then, the relative cost-effectiveness of the aircraft-glide combination is

$$R = 2\left(\frac{c}{c_G}\right)\left[\frac{\frac{D}{V} + \tau}{D\left(\frac{1}{V} + \frac{1}{V_G}\right) + 2\tau}\right]\left[\frac{G + L - f\left\{D\left(\frac{1}{V} + \frac{1}{V_G}\right) + 2\tau + r\right\}}{U - f\left(2\frac{D}{V} + 2\tau + r\right)}\right] \qquad (7a)$$

where c_G = cost per operating hour of the aircraft-glider system and
V_G = the maximum velocity at which the fully fueled aircraft can tow.

If takeoff and landing times are negligible and no fuel reserve is required,

$$R \approx \left(\frac{c}{c_G}\right)\left(\frac{2\,V_G}{V + V_G}\right)\left[\frac{G + L - f\,D\left(\frac{1}{V} + \frac{1}{V_G}\right)}{U - 2\frac{fD}{V}}\right] \qquad (7b)$$

C. Results

1. Powered Flex-Wing Aircraft

Exhibit 20 summarizes the results of model calculations involving the 1,000-pound-payload powered flex-wing aircraft. The entry R's were calculated using minimum cost ratios and the results are therefore conservative with respect to the flex wing. Minimum and maximum cost ratios are also presented so "optimistic" R's may be easily estimated.

The conditions represented cover the missions of Section III as well as a few more "points" that serve to test the sensitivity of the results to the "arbitrary" values of the missions.

The calculated values for official visits, litter evacuation, reinforcements, routine resupply, and command visits were obtained using the basic haul models. τ and r were taken as zero, but values for the other model parameters from the missions entries under "many" or "∞" were obtained using the (c) equations of this group whereas other entries were obtained from the (a) equations.

Rapid-reaction calculations were made with Equation (3) taking τ as 0, ϵ as 0 for helicopters and 1/60 for fixed-wing aircraft, and ϵ_0 as 1/60. For the 10-man operation, λ was taken as 1/6 and δ as 1/10; for the larger operations, $\lambda = 1/2$ and $\delta = 1/6$. The results are, of course, sensitive to these values but the choices are felt to be reasonable.

Line inspection entries were calculated using Equation (4c) as were those for aerial spray and aerial surveillance. This points up the fact that apparently different missions reduce to identical ones functionally if takeoff and landing times represent a sufficiently small portion of total mission time.

Cost-effectiveness measures for artillery direction are based on a mission of 2 hours' duration over the target. No significant changes would be expected if this value were varied from 1 through 5 hours. Shorter missions tend to reduce the flex wing's advantage.

Convoy control entries are derived from Equation (6c) using mission data from Section III. In this case D and τ are both taken to be equal to zero.

CIVIC ACTIONS											
			R_{MIN}								
COMPETITIVE SYSTEM	COST RATIOS		OFFICIAL VISITS		EVACUATION OF LITTERS				LINE INSPECTION	AERIAL SPRAY
	MIN	MAX	1 or 2	5+	1	6	10	MANY		
U-6A VS 1000 LB FLEX-WING	3.1	5.0	1.5	0.8	1.5	2.3	2.5	3.0	1.5	1.5
U-1A " " " "	4.2	7.5	2.1	1.1	2.1	1.1	1.4	1.4	2.1	2.1
LOH-5A " " " "	7.4	11.6	4.3	4.3	4.3	12.9	14.3	17.2	4.3	4.3
UH-1D " " " "	19.4	30.7	10.9	5.4	10.9	5.4	7.2	7.2	10.9	10.9

MILITARY ACTIONS																
	R_{MIN}															
COMPETITIVE SYSTEMS	REACTION OPERATIONS			REINFORCE-MENTS			ROUTINE RESUPPLY				COMMAND VISITS		AERIAL SURVEILLANCE	ARTILLERY DIRECTION	CONVOY CONTROL
	10	100	350	10	100	350	5300 LB	8300 LB	14,400 LB	∞	≤3	≤6			
U-6A VS 1000LB FLEX-WING	1.0	1.3	1.3	1.5	1.5	1.5	0.9	0.9	0.9	0.9	1.5	1.5	1.5	2.9	2.7
U-1A " " " "	0.6	0.9	0.7	1.1	1.3	1.3	0.9	0.9	0.7	0.8	2.1	2.1	2.1	4.0	3.7
LOH-5A " " " "	5.4	4.1	1.6	8.6	8.6	8.5	3.4	3.6	3.5	3.5	4.3	8.6	4.3	7.0	6.7
UH-1D " " " "	3.2	2.6	0.9	5.4	5.7	5.5	4.3	2.9	3.3	2.9	10.9	10.9	10.9	18.3	17.4

EXHIBIT 20 - POWERED FLEX-WING EVALUATION

Many entries are averages since they apply to different conditions. All averaging was acco .plished by weighting for mission frequencies, though it must be remembered that these are measures of likelihood in only a limited sense.

2. Towed Flex-Wing Gliders

Exhibit 21 summarizes the key points of the calculations performed to test glider cost-effectiveness. Values of R were calculated using Equation (7b) and minimum cost ratios. The two points selected for each comparison define the essentially linear portions of the R, D curves. Greater distances would require fuel tank modification or auxiliary tanks, either of which would invalidate the model used. At D values less than 25 miles, the curves slope upward and favor the glider configuration.

The results are unimpressive and this fact is obviously not due to cost considerations. In fact the results would not change much if the cost considerations were ignored. If r is assumed equal to 0.5 and $\tau = 0.1$, the glider's performance is enhanced but not to any significant degree.

As a payload supplementer, the gli. r appears to be deficient because of the system speed decrease it imposes. It was considered worthwhile to investigate the possibility of increasing system speed by decreasing payload, and the following analyses were performed:

Analysis a. A U-6A/glider combination was investigated in which half of the maximum glider payload was carried by the aircraft and half by a smaller glider. A second condition was investigated in which the entire weight normally carried in the glider was loaded in the aircraft. Structural strength limitations might prohibit this but an examination of the densities of military air-transportable items indicated that available cargo space would not. Odd-size cargo, of course, is not the issue. Clearly, it would be more suitable to the flat pallet deck and open sides of the glider.

Tow velocities and takeoff runs were calculated using the methods described in subsection IV. B. Velocity results are shown in Exhibit 22. For convenience the curve is plotted in ton-miles per hour, the product

	D(G) MAX	COST RATIO		$R_{MIN.}$	
	N. MI	MIN.	MAX.	25 N. MI.	D_{MAX} (G)
U-6A VS. U-6A WITH 2000 LBS.	230	0.89	0.94	0.84	0.62
U-1A VS. U-1A WITH 2000 LBS.	215	0.92	0.96	0.70	0.54
LOH-5A VS. LOH-5A WITH 2000 LBS.	140	0.95	0.97	1.02	0.87
UH-1D VS. UH-1D WITH 8000 LBS.	125	0.96	0.98	1.28	1.39

EXHIBIT 21 - FLEX-WING GLIDER EVALUATION

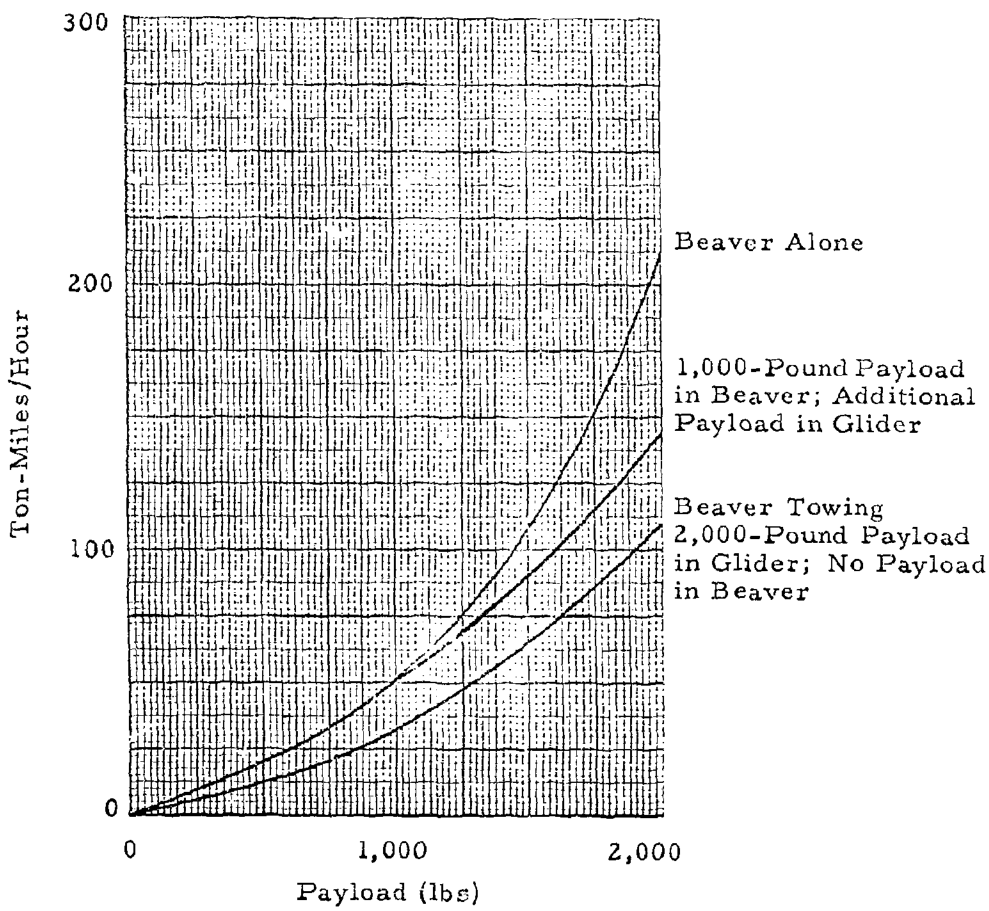

EXHIBIT 22 - BEAVER HAULING CAPABILITY OPTIMIZATION

of velocity and payload. For equal payload, ton-miles per hour is a direct measure of mission effectiveness and it is apparent that the overloaded aircraft is the most efficient configuration. For this condition, the Beaver requires a takeoff run of 680 feet and 1,230 feet to clear a 50-foot obstacle. Both of these values represent significant improvements over the takeoff performance of the aircraft-glider combination.

Analysis b. A similar analysis was performed using the LOH-5A. The results are illustrated in Exhibit 23 and thev suggest the overloaded helicopter as the optimum cargo delivery system rather than a glider combination.

The helicopter in the overloaded condition requires a takeoff run to get airborne. Using it in this manner would necessitate the substitution of wheels for skids, but then its takeoff performance would be admirable. Two takeoff conditions were analyzed. In one, the takeoff run was limited to 600 feet, the same distance required for the glider. In this case the overloaded aircraft can clear a 50-foot obstacle in 1,025 feet, a savings of 300 feet over the 2,000-pound-payload glider. On the other hand, if the landing strip is short, the overloaded helicopter can get by with no more than 300 feet. But this is at the expense of climb rate and would require 1,750 feet to clear an obstacle.

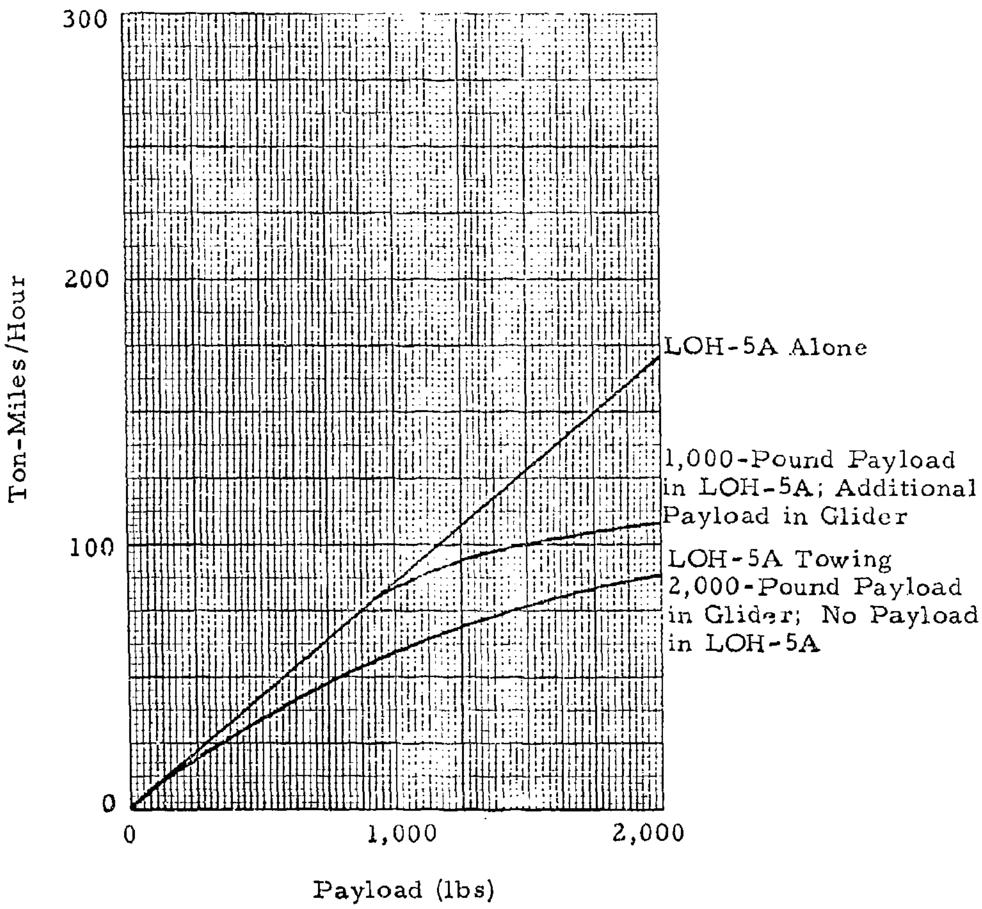

EXHIBIT 23 - LOH-5A HAULING CAPABILITY OPTIMIZATION

DEPARTMENT of DEFENSE

Directorate for Freedom of Information and
Security Review, Room 2C757
1155 Defense Pentagon
Washington, DC 20301-1155

Facsimile Transmittal

30 November 2001

To: **Mr. Larry Downing**

Organization: DTIC
Office Phone:
FAX Number: (703) 767-9244

From: **Sharon Reinke, Navy Division, DFOISR/WHS/DOD**

Phone: (703) 697-2716
FAX: (703) 693-7341

Total Pages Transmitted (including cover sheet): 04

Comments: I am forwarding the FOIA request DTIC received, the DTIC forwarding letter, and a list of documents. The documents in the attached list have been released to a FOIA requester [under our case number 01-F-2458] and are, therefore, cleared for public release. If you have questions, give me a call.

AMERICAN LAWYER MEDIA
105 MADISON AVENUE, NEW YORK, NY 10016
212-779-9200

01-F-2458

April 11, 2001

Defense Technical Information Center
Attn: Kelly Akers, FOIA Manager
8725 John J. Kingman Road Suite 0944
Fort Belvoir, VA 22060-6218

FOIA REQUEST

Dear Ms. Akers:

American Lawyer Media respectfully requests, under the Freedom of Information Act, a copy of each of the following records:

AD B253477, XV-8A Flexible Wing Aerial Utility Vehicle, by H. Kredit, January 1964, 144 pages

AD B252433, Pilot's Handbook for the Flexible Wing Aerial Utility Vehicle XV-8A, March 1964, 52 pp

AD B200629, Flex Wing Fabrication and Static Pressure Testing, by Larry D. Lucas. June 1995, 80 pages

AD B198352, Materials Analysis of Foreign Produced Flex Wings. by Albert Ingram, march 1995, 16 pp.

AD B131204, Active Flexible Wing Technology, by Gerald D. Miller, Feb. 1988, 256 pages

AD B130217, Producibility Analysis of the Alternative Antitank Airframe Configuration Flex Wing. June 1988, 112 pages

AD B126450, From Delta Glider to Airplane. June 1988, 5 pages

—AD B803668, Sailwing Wind Tunnel Test Porgram, September 1966, 125 pages

AD 477 482, An Evaluation of Flex-Wing Aircraft in Support of Indigenous Forces Involved in Counterinsurgency Operations by R.A. Wise, Feb 1965, 74 pages

—AD 461202, XV-8A Flexible Wing Aerial Utility Vehicle, H. Kredit, Feb. 1965, 100 pages

—AD 460405, XV-8A Flexible Wing Aerial Utility Vehicle. Final Report. Feb. 1965, 113 pages

—AD 431128, Operational Demonstration and Evaluation of the Flexible Wing Precision Drop Glider in Thailand, by William R. Quinn, November 1963, 22 pages.

AD 430150, Comparative Evaluation of Republic Bikini Drone System, Final Report, 1943?

We agree to pay up to $200 for costs associated with this request. We are grateful for your kind assistance in this matter. Please contact me at 212-313-9067 if you have any questions relating to our request.

Sincerely,

Michael Ravnitzky
Editor

Encl 1