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STUDIES RELATIVE TO THE DEVELOPMENT OF A ONE-MAN HELICOPTER
Part I

30 September 1953

HUGHES AIRCRAFT COMPANY

Culver City, California

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Part I

30 September 1953

for
Office of Naval Research
Department of the Navy

HUGHES AIRCRAFT COMPANY
Culver City, California

CONFIDENTIAL

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SUMMARY

The results of discussions with various military agencies, regarding possible missions and mission requirements, are presented. From these discussions it appears that the article of most interest in the one-man helicopter class is a portable machine, preferably of the back-pack type.

To investigate the feasibility of a portable one-man helicopter, studies were made of machines powered by various types of power plants. The results of these studies are presented herein in the form of charts of Maximum Range vs Empty Weight and Design Gross Weight.

As a criterion of feasibility it is assumed that the machine must have a stripped empty weight not exceeding 100 pounds, and a maximum range without reserves, based on design gross weight, of not less than 10 nautical miles. Cruising speed is assumed to be 45 knots.

The results of the studies indicate that only machines powered by either a tip-mounted rocket or a ram-rocket will meet the requirements. In all cases stripped empty weight includes weight allowances for stabilization and for a ground support strut (2½% of Design Gross Weight for each item) but does not include fuel tanks. Weight of pilot plus equipment is assumed to be 225 pounds. Both machines meeting these requirements have empty weights exceeding 90 pounds. The effect of assuming a weight of 240 pounds for pilot plus equipment is to increase empty weight in both cases to approximately 100 pounds.

The conclusions stated above are based on preliminary data that is believed to be realistic and probably attainable. It is probable that by using an unconventional design approach combined with a reduction in design criteria appreciable reductions in airframe weight may be attained. A study is reported herein, based on a conscious effort to go to extremes in assuming possible reductions in airframe weight. The resulting empty weight, for the machines

powered by tip-mounted rockets and ram-rockets having a maximum range of 10 nautical miles, is of the order of 60 pounds. The acceptable machines designed to reduced criteria will probably have empty weights somewhere between this value and the 90 to 100 pounds reported above.

It should be noted that the monopropellant rocket fuel employed is assumed to have a specific impulse of 180 seconds, and that the ram-rocket specific fuel consumption is assumed to be 12 pounds/pound thrust/hour. Any changes in these assumptions will appreciably affect the results regarding range and empty weight for a given design gross weight.

For the very light machines discussed above, it is interesting to note that weight of airframe plus fuel plus tanks for a range of 10 nautical miles is approximately the same (about 125 pounds) for the machines powered by rockets, ram jet, or pulse jet. The corresponding weight for the ram-rocket helicopter is 100 pounds.

It is possible that the definition of portability based on empty weight less fuel package will prove unrealistic, and that to be portable the airframe plus fuel and tanks must weigh 100 pounds or less. In this case only the ram-rocket configuration based on considerable deviation from Military Specifications meets the requirement at a range of 10 nautical miles; as pointed out in the text, a tip-mounted ram-rocket power plant is yet to be developed. All other configurations must then be transported on wheels when on the ground, whether hand-towed or moved by a vehicle. With the portability requirement eliminated as an item of consideration, the choice of configuration depends on the operational flexibility of the geared drives against the relative mechanical simplicity of the tip drives. With the geared drives the problem of ground transportation may prove relatively unimportant, due to their low cruising fuel consumption in flight.

INTRODUCTION

This report presents the results of Part I of a program entitled "Studies Relative to the Development of a One-Man Helicopter", authorized by Amendment 1, Contract Nonr 611(00).

Part I is concerned mainly with establishment of detailed requirements for missions. However, in the course of establishing mission requirements, it became evident that the configuration of most interest to the Military Services, in this class of machine, is one that is portable and, preferably, of the back-pack type. It was therefore considered desirable to determine approximate empty weights of helicopters as a function of maximum range at normal gross weight, based on feasible combinations of power plant and rotor configuration. This information may then be used to review the relative portability of each configuration.

It is of interest to present the definition of a one-man helicopter, as outlined in the Statement of Work of Reference 1:

".....the smallest rotary wing type aircraft which will:

1) transport one man
2) have satisfactory flight characteristics (performance, stability, and control)
3) accomplish a basic mission to be defined
4) have a minimum of instrumentation, and means for automatic maintenance of proper rotor speed and collective pitch for all flight conditions
5) be simple, cheap, capable of rapid assembly, and insensitive to poor servicing and exposure to weather".

SECTION I
ESTABLISHMENT OF DETAILED REQUIREMENTS FOR MISSIONS

1. Discussion

Preparatory to a study of mission requirements, various military agencies were contacted during the month of December 1952, and their views on the subject were requested. A series of possible missions were suggested, and specific questions were asked. The list of missions and the questions are given below:

Suggested Missions

a. Observation - Reconnaissance

b. Aerial Wire Laying

c. Liaison

d. Infiltration

e. Individual Deployment

f. Airborne Assault (Equivalent to Paratroopers)

g. Espionage

h. Resupply

i. Airborne Rescue

Specific Questions

1. What are the requirements of the Services with respect to each of the missions listed above?

2. Are there any missions which have not been included in the above list?

3. What type of mission would be suitable for a machine having a range of from 5 to 10 miles?

4. What ranges and what cruising speeds are considered desirable for each of the above missions, or others suggested?

5. What service life is required for the machine? Shall they be considered expendable items in any of the above missions?

Agencies Contacted (specifically regarding missions)

Army Transportation Corps - Ft. Monroe, Virginia
    Air Division R and D
    Airborne and Air Movement Br. - G3
    Air Division R and D (Ft. Eustis, Virginia)
Joint Amphibious Warfare Board - Little Creek, Virginia
USMC Air Equipment Board - Quantico, Virginia
Office of Naval Research - Washington, D. C.
    Air Branch
Bureau of Aeronautics - Washington, D.C.
    Aircraft Branch
    Rotary Wing Projects Branch
USMC Headquarters - Aviation - Washington, D. C.
USMC G3 - Aviation - Washington, D. C.
USA Infantry School - Ft. Benning, Georgia
Joint Landing Force Board - Ft. Lejeune, N. C.

2. Summary of Results - Requirements Specifications

No attempt will be made here to include all answers to the specific questions noted above. It is felt that more clarity will be achieved by first outlining certain specifications for a one-man midget helicopter, which reflect as nearly as possible a majority of views held in the military agencies. Where views are not generally conflicting, some discussion of the answers is then presented.

In general two somewhat divergent points of view were found to exist among the agencies contacted. The Aviation and Transportation Branches of the various Services consider only secondary missions for the one-man helicopter. For example, such missions as airborne rescue (air-droppable article), reconnaissance, column control, and liaison were considered. Some Infantry branches, however, regard the machine as having considerable potential as a vehicle for airborne assault. In the great majority of cases it is considered imperative that the machine shall be transportable - if possible "readily" transportable - by one man. A typical Requirement Specification, suitable for the airborne assault vehicle, is outlined below. This specification was written by USMC agencies, and expresses requirements both for an acceptable interim vehicle and the desired article.

REQUIREMENTS FOR PORTABLE ONE-MAN HELICOPTER

ITEM	INTERIM	OBJECTIVE
Cruising Speed (knots)	45	45
Endurance (minutes)	10 - 15	30
Range (nautical miles)	7 - 10	20
Best Rate of Climb (feet per minute)	300 - 500	1000
Service Ceiling (feet)	3000 - 5000	10,000
Payload (pounds)	240	240

Additional Requirements:

The machine shall be transportable by one man; it shall be cheap, and simple to maintain, assemble, and disassemble. It shall stand up to rough handling under battle conditions. Fuel should not present a serious logistics problem. The machine shall not be tricky to fly, nor present a serious problem in training the pilots. It shall be possible to make a safe landing in the standing position, and to remove the machine from the body with safety immediately after landing.

The foregoing Requirements Specification is directed mainly toward the procurement of a machine for Missions f and i (paragraph 1) the choice of mission depending, as previously indicated, on the specifying agency. In these missions portability by one man is regarded as essential, while a relatively short range is acceptable. In varying degrees the machine may also be used for the other suggested missions, but for "motorcycle" type duties, including column control, observation, and reconnaissance, it appears that somewhat more endurance is required; as is the ability to carry some radio communication equipment. While it should be emphasized that no requirement has been written for a one-man helicopter of this type (it is the view of some military agencies that a two-man ship is preferable) a suggested specification is outlined below:

SUGGESTED REQUIREMENTS FOR NON-PORTABLE ONE-MAN HELICOPTER

ITEM	PERFORMANCE
V cruise (knots)	45
V max (knots)	85
Endurance (minutes)	45
Range (nautical miles)	30
Best Rate of Climb (feet per minute)	1000
Initial Vertical Rate of Climb (feet per minute)	750
Hovering Ceiling (Out of Ground Effect - feet)	3000
Service Ceiling (feet)	10,000
Payload (pounds)	300

Additional Requirements:

The additional requirements of the portable one-man helicopter also apply to this machine, with the obvious exception of portability.

3. Additional Missions and Comments on Suggested Missions

In addition to the suggested missions outlined in Paragraph 1, additional missions were suggested by various military agencies as follows:

j. Column Control (of traffic on the march)

k. Radioactivity Monitors

l. Drones for radio and radar beacons

m. Withdrawal of rear guard and delay tactics during retreat

n. Forward air control

o. Pursuit and destruction of guerrilla forces.

The following comments are of interest with regard to the suggested missions listed in Paragraph 1.

a. Observation - Reconnaissance -- The portable machine would be useful for transporting observers to suitable observation points or for providing unit commanders with information on local conditions. For more conventional missions the two-man machine appears more suitable, since required communications equipment is considerable compared to gross weight of the ship, and operation of equipment is a burden on the pilot.

b. Aerial Wire-Laying -- In general it is felt that larger machines must be used for this purpose; however, it is believed that the laying of short wires to company OP's and to FO parties may be feasible.

c. Liaison -- The portable machine would be useful for commanders of regiments and lower units.

d. Infiltration -- For Commando type units the machine appears to have use in infiltration tactics, but noise and flash from power plants could be a disadvantage. Since, as shown in Figure 3, all of the possible configurations in the portable machine require the use of tip-mounted power plants, the question of noise and flash must be considered.

e. Individual Deployment -- The Services are generally dubious with regard to the feasibility of command and control of such an operation carried out with the use of one-man helicopters.

f. Airborne Assault -- As stated in the discussion of the Requirements Specification for the portable one-man helicopter, some agencies feel very strongly that there is a requirement for this machine, for use in airborne assault missions. In view of the operating personnel visualized, flying qualities requirements will be very stringent. This implies the necessity of including provisions for stabilization.

g. Espionage -- A machine which can be easily hidden in enemy territory and, if possible, used for the return trip, is essential. The portable machine is indicated. The relatively short range called for in this machine appears to be a drawback. However, it has been pointed out that the agent is not likely to head directly to his objective, but will attempt to reach a secluded point inside enemy territory from which he can proceed on foot to a contact point or to his objective. Thus the machine may be used only for a stage of the journey.

h. Resupply -- The Service agencies did not see any use for the one-man midget helicopter in this regard. The mission was originally suggested, however, with the thought of first-aid supplies in mind.

i. Airborne Rescue -- As stated previously, the concept is that of an air-droppable item, and is more strongly supported by Aviation than by Infantry agencies. The need is for a machine which can be very quickly assembled, and will transport a downed pilot out of the immediate danger zone. It is assumed, in the case of the USMC, that the pilot has had helicopter training, so that the flying qualities requirements are less stringent than those for the airborne assault machine.

4. Answers to Specific Questions

As stated previously, it is not considered necessary to detail all answers obtained. Such comments as are of note are given below.

a. Requirements -- With the exception of the Specification outlined in Paragraph 2, no official requirements exist for the one-man midget helicopter. The previous discussions have attempted to outline considerations which may influence the writing of specifications.

b. Other missions are outlined in Paragraph 3.

c. With regard to range, the minimum requirements should be for a machine that will transport troops across the opposing battle lines. Five miles plus reserves would appear to be the absolute minimum, with allowance for air assembly and maneuver. The equivalent would be about 10 miles without allowance for reserves (nautical miles are referred to here).

d. With regard to cruising speeds, it must be emphasized that no windscreen is visualized for use in the machine, since the portability requirement is compromised by the addition of any items not essential to flight. Tests of human subjects in the wind tunnel are reported in Reference 2. It is the opinion of these subjects that sustained exposure to the airstream at velocities in excess of 50 mph results in considerable discomfort and fatigue. Thus the cruising speed of 45 knots specified in the requirements for the portable one-man helicopter appears reasonable. The fuel rate at 45 knots is in any case within about 5% of fuel rate at speed for best range in all the configurations studied.

e. No clear answers were obtained with regard to service life, and military agencies were understandably reluctant to consider the machines as expendable, even in assault operations. It is revealing to note that 100 missions each involving 15 minutes operating time total only 25 hours. One hundred missions per machine appears improbably high, when considering assault operations; on the other hand, 25 hours is of the order of service life considered for such relatively expendable items as target drone power plants. No cost figures are yet available for a one-man midget helicopter, produced in quantity, nor is data available in this study to compare the cost of paratroop operations with those of an assault group using midget helicopters. It would be desirable however, to compare these costs, based on a first cost of $5,000.00 per helicopter, and taking into account operating cost (including losses in combat) of paratroop transports and air bases.

It is intended to make cost studies of typical midget helicopters during the course of this study. The $5,000.00 figure quoted above is based on preliminary estimates for a machine powered by tip-mounted power plants, assuming all development costs are charged against development contracts rather than against the production article.

SECTION II
PRELIMINARY REVIEW OF POSSIBLE CONFIGURATIONS

1. Effect of Portability Requirement

In an attempt to determine some of the implications of the Requirements Specification for the portable one-man helicopter, a preliminary study was made of machines designed to meet the specification. The results of this study are presented in Figure 3, in the form of curves of Range vs Gross Weight, and Range vs Empty Weight for the various machines. It will be pointed out in the discussion which follows that several types of power plants are eliminated by the requirement of portability, and those that are not ruled out are of the tip-mounted type. This finding has been borne out by experience. Several attempts to build a portable one-man helicopter using reciprocating power plants have resulted in machines which are underpowered; increase of power available would, of course, increase the weight. In these machines the typical empty weight was about 85 pounds, and gross power about 15 horsepower. Provision of sufficient additional power to give adequate performance would bring empty weight without landing gear up to around 180 pounds, which is beyond the range of portability.

It is desirable to define portability. It could be defined in any of the following terms:

The maximum load an average man can support on his back, while carrying defined items of battle equipment.

The maximum moment about his cg that a man can withstand without undue contortion, while standing on the ground.

The maximum load, or moment about the cg, whichever is critical, that a man can withstand when landing at a given descent velocity. (It would be assumed that the rotor is carrying some portion of the gross weight during the touchdown.)

A program is currently in progress, directed by Dr. Barry King, Research Executive, Aero-Medical Division, CAA, to study the aero-medical problems connected with piloting of midget helicopters. During the latter part of April 1953 limited tests were started in an effort to establish some of the foregoing criteria. A summary of the results to date is given below:

a) In the tests, the subject was dropped at approximately constant velocity (accelerations not exceeding one ft/sec^2), and carrying a back-pack harnessed to his body. The weight of the back-pack was not allowed to come onto the harness until the instant of impact. The center of gravity of the load was 4 inches behind the cg of the subject. Impact velocities varied between 3.8 and 6 fps, corresponding to the velocities attained in free fall from a range of 8 to 10 inches. (As mentioned above, however, accelerations permitted were negligible.) The subject chosen for the tests is considered to have physique and stamina that are above average. The landing floor was smooth and flat.

b) It was found that the maximum weight that could be tolerated without falling backward was 131 pounds above body weight. The impact was taken stiff-legged. Any attempt to squat when taking impact resulted in falling backward. In one case where a landing was inadvertently made at 16 fps velocity, the subject fell heavily and was unable to use his legs for several minutes thereafter.

c) In cases where the subject aided his balance by carrying a 16-pound bar at arm's length in front of his body, he was able to bend the knees and squat down on landing when carrying approximately 100 pounds above his body weight. This points up the importance of center of gravity position when landing on rough terrain, where some freedom of body motion is highly desirable during and immediately following impact.

If the average midget helicopter pilot is assumed to weigh 180 pounds, and to carry 45 pounds of clothing and equipment, it appears from the information presented above that the empty weight of the machine should not exceed 86 pounds. Studies of one-man helicopter designs indicate that a 4- to 6-inch cg offset (aft) is reasonable. (Note that an equivalent moment about the cg of the pilot could also be approximately simulated by a 100-pound rotor thrust load tilted 10 degrees aft of the vertical.) It is therefore conservative to assume, in the discussion which follows, that the upper limit of portability is reached at an empty weight of 100 pounds for the midget helicopter.

2. Estimation of Empty Weights

The following assumptions will be made in estimating empty weight:

a) All machines will be considered in stripped-down condition, without conventional landing gear, or fuel tanks. The concept is that of a back-pack machine to which a fuel package may be attached before take-off. Fuel tank weight, while a relatively small item in the case of conventional power plants, is likely to be considerably more important in monopropellant systems. Since weight of fuel plus tanks for the rocket powered machine will be of the order of the machine empty weight, the two items together are likely to weigh in excess of 150 pounds -- obviously not a portable item. It is, however, reasonable to assume that the machine will be provided with a support strut, both to assist in taking landing shock and to support the back-pack while the fuel tank is being attached. The tank plus fuel is treated as a Supply item, to be delivered in quantity at the jumping-off point, or dropped separately from the machine for airborne rescue.

b) It will be assumed that the machine may be built for an empty weight, not including power plant and drive system, landing and support structure, or fuel tanks, of 18% of design gross weight. The following is an assumed weight breakdown for a 375-pound machine, using optimum weight figures:

Pylon, harness and empennage	22 pounds
Rotor blades	12 pounds
Hub and blade retention	20 pounds
Controls	12 pounds
Instruments	3 pounds
Total	69 pounds

Since 69 pounds is 18.4% of 375 pounds, it is seen that the 18% allowance for the above items is reasonable.

It is of some interest to review briefly the basis for the assumption of 22 pounds for pylon, harness, and empennage. The Hoppicopter Model 101 body harness and pylon structure weighed 22 pounds for a machine having a gross weight of 289 pounds. In a recent design for a one-man helicopter powered by tip-mounted rockets, the harness, pylon, and empennage weighed approximately 22.5 pounds. It should be noted that the Hoppicopter, being a coaxial, did not have an empennage; however, the pylon was designed for mounting of a reciprocating engine, and thus was heavier than the pylon for the rocket-powered machine, although the latter has a design gross weight of 375 pounds.

c) It is assumed that the landing and support structure mentioned in Paragraph 2b) weighs 2½% of gross weight. An additional 2½% allowance is made for stabilization provisions. In view of the comments in Paragraph 1a) it appears highly desirable to provide some means for obtaining acceptable flying qualities of the one-man helicopter. It should not be inferred, however, that an autopilot is necessary or even desirable. Recent studies, which will be discussed in a later report, indicate that adequate flying qualities may be obtained by use of tip weights on the rotor blades and a horizontal tail. For these items, the assumed weight allowance is reasonable, and in the case of the machines powered by tip-mounted engines possibly conservative.

d) The following assumptions are made in determining weights of power plant, fuel tanks, and fuel. These assumptions are again based on data currently available. Note that the weights do not include starting and cooling provisions.

Power Plant Type	Sp. Weight (Installed) lb/hp	Sp. Fuel Consumption lb/hp-hr	Tank Wt. / Fuel Wt.
High-output reciprocating	1.4	1.0	0.05
Conventional gas turbine	1.4	1.4	0.05
Monopropellant turbine (stored oxidizer)	0.6	6.0	0.10
Monopropellant turbine (double react.)	1.1	2.0	0.10
Pressure jet (cold air bleed)	1.6	3.5	0.05
	lb/lb Thr.	lb/lb T/hr	
Tip-mounted rocket	0.1	20	0.10
Pulse jet - conventional	0.5	9	0.05
Pulse jet - ducted	0.85	7	0.05
Ram jet - conventional	0.40	12	0.05
Ram-rocket	0.3	12	0.10

Assumed values of net power loading of the main rotor are based on a requirement of 750 feet per minute initial vertical rate of climb. This requirement will also permit a hovering ceiling out of ground effect of approximately

5000 feet in the case of air-breathing power plants, higher for monopropellant powered machines. Although the machines may well be used in mountainous territory under unfavorable ambient conditions, this should provide a suitable margin of power.

The reciprocating power plant assumed for the example is assumed to be a high-speed, two-stroke engine, designed for relatively short life (target-drone type of power plant). The fuel is a combination of gasoline and oil, so that no separate oil system is required.

The monopropellant turbine is assumed in two configurations:

a) Single reaction -- the propellant drives a single turbine wheel to develop shaft power. High efficiency is assumed, resulting in a HP_{sp} of 600 seconds or 5 pounds per horsepower-hour.

b) Double reaction -- the propellant, after leaving the first turbine stage, is mixed with air and burned. The products of combustion are used to drive a second-stage turbine. A HP_{sp} of 1800 seconds (2 pounds per horsepower-hour) is assumed for this configuration. The figures are chosen with a view to indicating the optimum possible results obtainable with the use of this type of power plant.

Weight estimates for the monopropellant turbines are based on preliminary designs for these power plants. It may be possible to effect a considerable reduction in the combined weight of engine plus gearing of type a), but such an assumption would be premature until more detailed investigations have been made.

The **ram-rocket** may be crudely described as a combination of rocket and ram jet power plants. The rocket nozzles are placed just aft of the diffuser of a shell similar to that of a ram jet. The products of decomposition of the monopropellant rocket fuel are mixed with the air entering the shell, and burned. Obviously, at low rotor tip speeds the engine operates almost entirely as a rocket; at very high tip speeds the operation approaches closely that of the tip-mounted ram jet. Assuming that the cruise specific fuel consumption of the power plant is equal to that of the tip-mounted ram jet, the ram rocket has two obvious advantages for a helicopter power plant, when compared to the ram jet. These are a smaller shell, resulting in a reduction in weight and cold drag of the shell; and the ability to accelerate from zero rotor speed without external means. (The lower shell cold drag will reduce the power-off descent rates of the machine.)

The figures assumed for the ram-rockets are based on the following considerations:

a) The unit is assumed to have multiple nozzles and low L/D (duct fineness ratio) to obtain satisfactory mixing without the weight penalties associated with a long duct on a whirling arm. A fuel-air ratio (R^*) of 15 is assumed. Reference 3 indicates that for $M - .6$, $R^* = 15$, TSFC is approximately 8.0. However, all data given in this reference appears quite optimistic, apparently because mixing losses are not included in the analysis. Comparing the ram jet and pulse jet performance data presented in Reference 3 with information on power plants currently operating, it appears reasonable to apply a factor of at least 1.5 when selecting values of TSFC from the Reference. The ram-rocket TSFC is therefore assumed to be 12 pounds/pound T/hour, in the cruise configuration.

b) Since a low L/D (about 3) is assumed, the dimensions of the ram-rocket duct will be somewhat similar to those of a ram jet. From Figure 3 of

Reference 3 it is seen that at $M = .6$ the thrust per unit cross sectional area of the ram-rocket for a given thrust is about 30% less than for a corresponding ram jet; diameter is about 18% less. Thus the assumption that the ram-rocket power plant weighs 25% less* than the corresponding ram jet power plant may be somewhat optimistic in favor of the ram-rocket, especially since a rocket chamber is included in the latter.

c) Fuel rates in pound per nautical mile for the ram-rocket are, on the basis of assumption a), assumed identical with those of the ram jet, as presented in Figure 2. The assumption is implicit that the rotor configuration and tip speed are identical for both types of power plant. In view of other uncertainties involved, regarding power plant weight and TSFC, further refinement is not considered reasonable.

The following is assumed with regard to rotor dimensions for the various machines:

a) A disc loading of 2 pounds per square foot is assumed in all cases. This is chosen as a compromise between desirable minimum rates of power-off vertical descent and practical values of rotor diameter.

b) Untwisted, rectangular blades are used in all cases.

c) All machines are of single lifting-rotor configuration. In the case of the geared drives a tail rotor weight is included in the weight estimates. In the case of the tip-mounted power plants no tail rotor is assumed, although indications are that it will prove necessary for control in flare-outs close to the ground. It should be mentioned that a small tail rotor, adequate for the

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* In terms of specific weight

directional control requirements of a one-man helicopter with tip-mounted power plants, can be substituted for a vertical fin of adequate dimensions with little, if any, weight penalty. (This has proved true on small helicopters currently in operation.) It should also be noted that the 22.5-pound pylon weight for the rocket-powered machine includes allowance for tail boom and empennage. Thus the empty weight estimates herein may be assumed to include a tail rotor for tip-powered machines, when the tail rotor is substituted for a vertical tail.

d) Design information:

POWER PLANT	DISC LOAD. (PSF)	SOLIDITY σ	TIP SPEED (FPS)	DESIGN C_T/σ	BLADE SECTION
Geared Reciprocating	2	.030	575	.087	.0015
Geared Gas Turbine	2	.030	575	.087	.0015
Ram Jet, Ram Rocket	2	.040	650	.049	.0015
Pulse Jet (Conventional)	2	.060	400	.085	.0015
Geared Monopropellant Turbine	2	.030	575	.087	.0015
Tip Rockets	2	.030	650	.065	.0015
Pressure Jet	2	.050	600	.046	.0018
Pulse Jet, Ducted	2	.040	500	.084	.0015

The above design characteristics were chosen on the basis of experience with current rotary-wing aircraft. A disc loading of 2.0 pounds per square foot was selected to permit reasonable vertical autorotation and flare-out characteristics. Where feasible, a design mean rotor lift coefficient of about .50 was used. This coefficient is given by

$$C_{Lr} = 6\ C_T/\sigma \qquad \text{where}$$

$$\text{Thrust Coefficient } C_T = \frac{\text{rotor disc loading}}{\text{air mass density x (tip speed)}^2} = \frac{w}{\rho V_T^2}$$

$$\text{Rotor Solidity } \sigma = \frac{\text{Blade area}}{\text{Disc area}}$$

The lower values of C_T/σ are used in the case of the ram jet, ram-rocket, pressure jet, and tip-mounted rocket. It was desired in these cases to keep tip speed up to take advantage of the jet thrust. Solidity values were dictated by autorotation requirements in the case of the ram jet and ram-rocket, aerothermodynamic requirements (required duct areas) in the case of the pressure jet, and by reasonable values of blade slenderness ratio in the case of the tip-mounted rocket.

3. Discussion of Results

In reviewing the results of the studies of Range vs Weight, it must be emphasized that these results are only true in terms of the assumptions made, particularly those concerning weight breakdown and specific fuel consumption. In general, the weight allowances made in this study cannot be said to be conservative; some deviation from conventional design criteria accompanied by very careful weight control will be required to meet these allowances. With regard to specific fuel consumption, the assumptions made were in all possible cases based on performance of helicopter power plants currently in operation. The exceptions are the monopropellant turbine and the ram-rocket, for which the bases for the assumptions are discussed herein (page 13).

The results of the studies are presented in Figures 3 and 4. The calculations are presented in Tables I through IV and are in general self-explanatory. The calculations of net rotor horsepower vs gross weight ratio, presented in Figure 1, are based on methods given in Reference 4. The data of Figure 1 was used in establishing weight allowances for power plants in Table I. (In a forthcoming Stage report under this Contract, charts for performance estimation, based on the methods of Reference 4, will be presented.)

Figure 2 presents curves of fuel rate in pounds per nautical mile vs gross weight for midget helicopters having suitable combinations of power plant and rotor configuration. A cruising speed of 45 knots is assumed in all cases, fuel rate at this speed being within 5% of optimum fuel rate for all configurations of this study. It is seen from inspection of Figure 2 that, for a given disc loading, the ratio of horsepower vs gross weight required to meet a specified vertical rate of climb is primarily a function of the rotor tip speed; the pulse jet, with the lowest tip speed selected for study, also has the lowest horsepower vs gross weight ratio. However, the pulse jet does not prove to be the optimum configuration from the standpoint of empty weight, as seen from Figure 3. The reason is found from inspection of Figure 2, where the specific fuel consumption of the pulse jet is shown to be relatively high compared with most other configurations selected for study.

Figure 3 presents curves of stripped Empty Weight and Design Gross Weight vs Maximum Range (no reserves) in nautical miles, for the configurations of midget one-man helicopters studied herein. It is assumed (see Paragraph II, 1 herein) that the maximum permissible empty weight that can be tolerated from the standpoint of portability is 100 pounds. (It is assumed that the pilot is already carrying 40 to 60 pounds of clothing and equipment.) It also appears reasonable to assume that the range without allowance for reserves shall not be less than 10 nautical miles. Reference to the curves of Figure 3 shows that only machines powered by tip-mounted rockets and by ram-rockets* will meet these requirements, with stripped empty weight for both configurations in the 90 to

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* In this regard refer to Paragraph II, 4, "Uncertainties Regarding Ram-Rocket Performance".

100 pound range. The design gross weights of all configurations lie between 350 and 435 pounds for a design maximum range of 10 nautical miles.

It is of interest to point out (Figure 1) that if the machines were operated at some overload gross weight to achieve a maximum cruising range of 20 nautical miles, the ratio Overload Gross Weight/Design Gross Weight would be approximately 1.25 for the rocket-powered machine, 1.18 for ram-rockets, and 1.04 for the reciprocating and gas turbine configurations. The ratios given for the rocket and ram-rocket configurations would seriously compromise performance at altitude.

The curves presented in Figure 3 are based on weight of man plus equipment weight of 225 pounds. Weight allowances were made for stabilizing provisions and for a ground support strut. The effect of changes in these items is shown in Figure 4 for the rocket configuration. It is seen that if man plus equipment is assumed to weigh 240 pounds, the empty weight for a range of 10 nautical miles increased from 95 to 102 pounds, an increase approximately half as great as the increase in payload. If the weight allowances for stabilization provisions and ground support strut are omitted, stripped empty weights are 68 pounds and 73 pounds for the 225-pound pilot and 240-pound pilot respectively. Since fuel plus tanks for the specified range will weigh about 90 pounds, harnessing of the structure and fuel package unassisted, without the use of some ground support member, hardly appears feasible. It is also likely, if the machine is to be flown by relatively unskilled personnel, in airborne assault operations, that some type of stabilization provisions will prove necessary.

The results of Figure 4 are proportionately applicable to the ram-rocket configuration.

It therefore appears that the weight allowances for stabilization provisions and for a ground support member should not be omitted from the estimates of stripped empty weight.

The results of the preliminary studies presented herein indicate that only the rocket and ram-rocket configurations can be built to achieve a stripped empty weight, not including fuel tanks, of less than 100 pounds, for a maximum range, without reserves, of 10 nautical miles. The assumptions made in arriving at these results are based on preliminary data that is considered to be realistic and probably attainable. An appreciable reduction in empty weight is possible by adopting an unconventional design approach combined with reduction in design criteria. The results of carrying this approach to extremes is discussed in Paragraph 5 and summarized in Figure 5.

4. Uncertainties Regarding Ram-Rocket Performance

The performance analysis of the ram-rocket is generally based on the study of devices having proportions such that reasonable assumptions may be made in the course of the application of classical fluid dynamic and thermodynamic theory. In the usual application, the ram-rocket is part of a missile-body wherein the geometry of the mixing-combustion chamber is adequate for the application of classical momentum mechanics between stations with a fair degree of assurity as to the accuracy of the results.

As matters now stand, the application of the ram-rocket to the driving of a midget helicopter rotor involves structural and weight limitations which militate against the predictability of internal performance. The engine must be short-coupled (that is, have an L/D ratio of the order of 3:1) in order to arrive at a shell structure which can withstand the high lateral loading and the result of this geometrical requirement is one which causes the internal flow phenomena to be of a type where theoretical means of performace estimation cannot be used rationally. Calculation then becomes meaningless.

In order to determine the nature of the aero-thermodynamic compromises which must be accepted, to yield a device which has adequate structural integrity, it is evident that some basic test investigations must be conducted in parallel with fundamental design theory. This approach may give, but in no sense guarantee, end results that will show the ram-rocket to be competitive as a tip-mounted power plant for the midget one-man helicopter.

The foregoing discussion, while applied to the ram-rocket, also describes the problems encountered and development program undertaken in the case of the tip-mounted ram jet. Judging by the history of ram jet development, an extensive program will be required to obtain an operational tip-mounted ram-rocket power plant.

5. Operation of Rocket-Powered Helicopter at High Subsonic Tip Speeds

It has been suggested that the rocket-powered helicopter should be operated at high tip speeds to obtain optimum performance. In the discussion which follows it is pointed out that this approach introduces serious problems in design of the rotor system. Any reduction in fuel rate is obtained at the expense of severe compromises in overall performance, and little if any reduction in empty weight.

At first glance it may appear that the optimum way to utilize the tip-mounted rocket is to operate at the highest possible rotor tip speed. Over the operating tip-speed range, rocket thrust does not vary, so that horsepower available from the rocket increases linearly with tip speed. At a cruising speed of 45 knots, for a typical case, rotor profile losses are about 40% of total power required, the remaining 60% consisting of induced and parasite losses. Since profile losses increase approximately as the cube of tip speed, an increase in tip speed from 600 fps to 800 fps (with no reduction in solidity ratio) while increasing power available by 33% will also increase the cruise profile losses by approximately 55% of total power required at the lower tip speed. Obviously then the solidity ratio must be decreased as tip speed is increased, to maintain profile losses approximately constant. The structural and aerodynamic problems involved when attempting to reduce solidity ratio are outlined briefly below.

When designing a rotor to operate at high subsonic tip speeds, the optimum overall performance is obtained when drag divergence on the advancing blade tip occurs at the same forward speed as drag divergence or stall on the retreating blade tip. In general, the maximum drag divergence Mach Number of an airfoil section occurs at the angle of zero lift, and its value increases with decreasing thickness of the section. However, the maximum lift coefficient of a section generally increases with thickness ratio. Furthermore, except for operation fairly close to zero lift, the lift coefficient (for a given Mach Number) at which drag divergence occurs increases with thickness ratio. (Over a wide range of lift coefficients the lift break and drag divergence occur at approximately the same Mach Number.) Thus the optimum rotor airfoil section for operation at high subsonic tip speeds must offer a good compromise between maximum zero-lift drag divergence Mach Number and maximum permissible lift coefficient (whether based on lift break or drag divergence). On the basis of airfoil section data currently available the NACA 0015 section appears to offer a favorable compromise, compared to other sections.

A study has been made, using the NACA 0015 section, to investigate the possibility of improving the fuel consumption of a one-man helicopter powered by ethylene oxide tip-mounted rockets, by optimizing rotor geometry at high subsonic tip speeds. This study will be presented in a later report. The results are summarized below:

a)	Design tip speed	750 fps
b)	Maximum forward speed (drag divergence on retreating blade)	87 fps (51 knots)
c)	Disc loading	2 lb/sq ft
d)	Blade solidity ratio	.018
e)	Blade chord - approx. (rect. blade)	2.25 in.
f)	Blade maximum thickness	0.34 in.
g)	Blade linear twist (washout)	-16 degrees

No consideration was given to taper in plan, since this would compromise the fabrication problem and offer little improvement in cruise performance. Obviously, the large twist required also results in fabrication difficulties. Since an error of 0.5° in tip angle of attack at V_{max} reduces drag divergence Mach Number on the retreating side by about 20 fps, it is seen that the limiting V_{max} can be seriously affected by an error in the twist. Such an error could conceivably be introduced by aeroelastic effects.

To obtain reasonably satisfactory hovering and cruise-speed flying qualities it is desirable, as will be shown in a later report, to provide about 3 pounds at the tip of each blade. The ethylene oxide rocket and its retention will, in any case, have approximately this weight. The centrifugal force at design tip speed due to a 3-pound tip weight is 6700 pounds; at 25% overspeed the centrifugal force is 10,500 pounds, and the blade must be designed for an ultimate load of 15,750 pounds. Working the tip material to an ultimate stress, due to centrifugal load only, of 45,000 psi, requires 0.35 square inch of material, and the solid blade area is approximately 0.50 square inch. Thus the tip section must be 60% solid, loaded to 100% efficiency, to operate as indicated above; inboard sections must be heavier yet. This introduces blade balance problems, which can possibly be solved by moving the engine well forward of the quarter chord. The latter solution in turn introduces large chordwise bending moments as well as engine retention problems.

The performance curves of Figure 3 herein, for the rocket powered machine, are based on a tip speed of 650 fps and a solidity ratio of .030. In a forthcoming report it will be shown that all-around performance is improved, with little compromise in fuel rate, at a tip speed of about 600 fps and a solidity ratio of .035, using a rectangular untwisted blade. It is not likely that any appreciable weight saving will result by increasing tip speed from 600 to 750 fps and reducing solidity ratio from .035 to .018, due to the structural problems introduced by the tip weights. (It should be noted once again that tip weight is highly desirable even if tip-mounted power plants are not used, to improve the flying qualities of the small helicopter.) An additional structural complication is introduced by the requirement for twisting the blade of the high-tip-speed rotor to obtain the performance presented above. The linear twist results in an inboard movement of the spanwise center of pressure of the blade, while the mass distribution is relatively unaffected. A large increase in the first harmonic flapwise bending moments results.

Preliminary performance calculations indicate that fuel rate may be decreased as much as 18% by increasing tip speed from 600 to 750 fps and reducing solidity from .035 to .018. However, airframe weight is not likely to be reduced appreciably, so that the portability will not be much affected by the changes in rotor configuration.

Thus it appears that in attempting to reduce fuel consumption of the rocket-powered machine by optimizing tip speed and solidity, serious difficulties in design and fabrication have been introduced, the maximum forward speed has been limited to slightly in excess of 50 knots, altitude performance compromised, and the handling qualities adversely affected. There are also indications that it may prove difficult to reduce power plant dimensions appreciably, so that some of the saving in fuel (possibly 50% or more) may be used up in increased power plant fairing drag losses.

6. Estimation of Minimum Possible Airframe Weights

The curves of weight versus range presented in Figures 3 and 4 are based on preliminary data that is considered to be realistic and probably attainable. Since the data was prepared, a careful review of the possibilities of weight reduction, based on design studies, has been made. A conscious effort was made to go to extremes in estimating the maximum possible weight reductions that might be made, resulting in empty weights that represent the lower limits of what is feasible in a practical design. The acceptable machines will probably have empty weights somewhere between these lower limits and the weights indicated in Figures 3 and 4.

It appears that a somewhat unconventional design approach combined with a reduction in design criteria may result in appreciable reduction in airframe weight. It is believed that the curves of Figure 5 represent the lower limit of possibilities in this direction.

A discussion of the reasoning upon which Figure 5 is based is summarized below.

1) Only tip-mounted power plants are considered. It appears from Figure 3 that portability cannot be achieved with the geared drives.

2) It appears that the airframe (less tip engines, landing gear, or fuel tank, but including empennage) may be built for an empty weight equal to 15% of gross weight. This represents approximately 17% reduction in airframe weight from the data used in preparing Figures 3 and 4.

3) Allowance for landing and support structure is reduced to 1.5% of gross weight. The structure is assumed to consist of a light telescoping strut sprung with shock cord, or the equivalent in design simplicity.

4) No allowance is made for stabilization provisions. Studies have recently been reported of methods for stabilizing small helicopters. As a result of these studies it appears that the hovering flying qualities may be considerably improved by use of tip weights on the rotor blades. Further studies, to be presented in a later report under this Contract, indicate that use of tip weights plus a horizontal tail will provide reasonably satisfactory flying qualities in forward flight. Since tip weights are already present in the form of tip-mounted power plants, and allowance for the empennage is included in item 2) above, no additional allowance is made.

5) Paragraph II, 5 summarizes the results of a study to determine the reductions in fuel rate and airframe weight possible as a result of optimizing rotor tip speed and solidity ratio. It was found that by increasing tip speed from 650 to 750 fps and reducing solidity ratio from .030 to .018 the fuel rate may be reduced approximately 13%. (The study, which will be presented in a later report, indicates that little is to be gained by further increases in tip speed.) It did not appear likely that any reduction in rotor weight would

result from the reduction in solidity, due to the increase in centrifugal loading and reduced section properties of the blade. The curve of fuel rate versus gross weight for the rocket-powered machine having a tip speed of 750 fps and a rotor solidity ratio of .018 is presented in Figure 2.

Figure 5 presents curves of airframe weight (without fuel tank) and airframe weight plus fuel plus tanks versus range in nautical miles. It appears that the rocket and ram-rocket configurations have a range of 10 nautical miles without reserves for an airframe weight (less tanks) of the order of 60 pounds compared to 82 pounds for the ram jet and 89 pounds for the pulse jet. All configurations except the ram-rocket have a weight, for airframe plus fuel and tank, of the order of 125 pounds; the corresponding weight for the ram-rocket is 100 pounds.

It is of interest to note that relatively little gain in portability is indicated as a result of optimizing the rotor tip speed and solidity of the rocket-powered machine as compared to operation at fairly conventional tip speed and solidity. This is especially true for a range of 10 nautical miles or less. On the other hand, considerable complication in design and fabrication may result if the optimization is attempted, as pointed out in Paragraph II, 5.

TABLE I

Estimation of Power Plant Weight to Gross Weight Ratio
Gross Weight = 400 Pounds   Disc Loading = 2.0 Lb/Sq Ft
Power Provided for $(R/C)_V$ Initial = 750 Ft/Min

Power Plant	Net Power Loading	Total Losses % HP	Gross HP Req	Tip Speed	Jet Thrust	PP Weight	PP Weight	PP Weight / Gross Weight
	Lb/HP *	* **	(400 Lb Machine)	FPS	Lb	Lb/HP (Est)	Lb/Lb T (Est)	
Tip Rockets	12.5	1	32.3	650	27.4		0.1	.007
Ram Jet	11.75	1	34.4	650	29.2		0.4	.029
Pulse Jet (Conventional)	14.7	1	27.5	400	37.8		0.5	.047
Ducted Pulse Jet	13.9	1	29.1	500	30.9		0.85	.066
Reciprocating	13.3	20	37.6	575		1.4		.13
Gas Turbine	13.3	15	35.4	575		1.4		.12
Monopropellant Turbine (Stored Oxidizer)	13.3	15	35.4	575		0.6		.053
Monopropellant Turbine (Double Reaction)	13.3	15	35.4	575		1.1		.097
Pressure Jet	11.5	1	35.1	600		1.7		.150
Ram-Rocket				650				.020 Assumed

* From Figure 1
** % of Gross Rotor HP, Including Following Losses: Gearing, Cooling, Tail Rotor

TABLE II

Estimation of Stripped Empty Weight
Various Power Plant Configurations
(As a Fraction of Design Gross Weight)

Item	Tip-Mtd Rocket	Ram Jet	Pulse Jet	Geared Piston	Geared Gas Turbine	Pressure Jet (Cold Bleed)	Monopr Turbine (Single React.)	Monopr Turbine (Dbl React.)	Ram Rocket
Basic Stripped Wt.	.180	.180	.180	.180	.180	.180	.180	.180	.180
Power Plant	.007	.029	.047	.130	.120	.150	.053	.097	.020
Cooling				.010					
Landing Gear Single Member	.025	.025	.025	.025	.025	.025	.025	.025	.025
Gearing and Drive				.050	.060				
Clutches				.020	.020				
Starting		.010	.010	.015	.010	.010			
Add'l Rotor Wt.		.030	.030			.030			
Stabilization System	.025	.025	.025	.025	.025	.025	.025	.025	.025
Tail Rotor and Dr.				.020	.020		.020	.020	
Total Empty/Gross	.237	.299	.317	.475	.460	.420	.363	.407	.250

TABLE III
Estimation of Maximum Range and Stripped Empty Weight for Selected Values of Design Gross Weight - Various Power Plant Configurations

Item	Reciproc. (Hi Output)		Gas Turb. Geared		Pulse Jet Conv.		Ducted Pulse Jet*		Pressure Jet		Ram Jet		Tip-Mtd Rocket		Ram-Rocket TSFC = 12	
Gross Weight	435	450	435	450	400	600	400	600	450	500	400	600	350	500	350	500
EW/GW (No Tanks)	.475	.475	.460	.460	.317	.317	.336	.336	.420	.420	.299	.299	.237	.237	.25	.25
UL Pounds	228	236	235	243	273	410	266	398	261	290	281	421	267	382	262.5	375
UL - 225 = (Fuel+Tank)	3	11	10	18	48	185	41	173	36	65	56	196	42	157	37.5	150
Fuel (Pounds)	28	10.5	9.5	17.1	45.6	176	39	164	34	62	53.2	186	38	41	33.8	135
Average GW	434	445	430	442	377	512	380	518	423	469	374	507	331	430	333	433
Fuel Rate Lb/N Mile	.40	.40	.59	.61	4.10	5.02	2.80	3.80	1.7	1.9	4.58	5.91	6.70	7.80	4.25	5.20
Range N Miles	7.5	26.3	16.1	28.0	11.1	35.1	13.9	43.2	20.0	32.6	11.6	31.5	5.7	18.1	7.9	26.0
Empty Wt (No Tanks)	207	214	200	207	127	190	134	202	189	210	120	179	83	118.5	87.5	125

Item	Monopropellant Turbine			
	HP_{SP}=600		HP_{SP}=1800	
Gross Weight	400	450	400	450
EW/GW	.363	.363	.407	.407
UL Pounds	255	287	237	267
UL-228 = (Fuel+Tanks)	30	62	12	42
Fuel=.9 (Fuel+Tanks)	27	56	11	38
Average GW (Pounds)	386	422	395	431
Fuel Rate Lb/N Mile	2.3	2.45	.75	.80
Range N Miles	11.7	22.9	14.7	47.5
Empty Wt Pounds	145	163	163	183

* NOTE: EW/GW same as for Pulse Jet, except difference in power plant Weight/Gross Weight ratio.

TABLE IV
Estimation of Maximum Range and Stripped Empty Weight
for Midget Helicopter Powered by Tip-Mounted
Rockets - Various Wt. Configurations
Cruise Speed = 45 Knots

Item	Stabilization and Landing Gear Provisions Incl (.05W Total)				No Provisions for Stabilization and Landing Gear			
	225-Lb Pilot		240-Lb Pilot		225-Lb Pilot		240-Lb Pilot	
Gross Weight	350	500	350	500	350	500	350	500
EW/GW (No Tanks)	.237	.237	.237	.237	.187	.187	.187	.187
UL Pounds	267	382	267	382	285	407	285	407
(UL - Pilot) = (Fuel + Tanks)	42	157	27	142	60	182	45	167
Fuel - Pounds	38	141	24	128	54	164	40.5	150
Average GW	330	430	338	437	323	418	330	425
Fuel Rate Lb/N Mile	6.7	7.8	6.80	7.85	6.6	7.65	6.7	7.7
Range - N Miles	5.7	18.1	3.5	16.3	8.2	21.5	6.0	19.5
Empty Wt (No Tanks)	83	118	83	118	65	93	65	93
Tank Wt - Pounds	4	16	3	14	6	18	4.5	17

TABLE V
Estimation of Optimum Feasible Stripped Empty Weight/Gross Weight Ratios
Obtainable by Deviation from Current Military Specifications
Various Tip-Mounted Power Plant Configurations

Item	Tip-Mtd Rocket	Ram Jet	Pulse Jet	Ram-Rocket
Basic Stripped Weight	.150	.150	.150	.150
Power Plant	.007	.029	.047	.020
Landing and Support Structures	.015	.015	.015	.015
Starting		.010	.010	
Additional Rotor Weight		.030	.030	
Total Empty/Gross	.172	.234	.252	.185

Table VI
Estimation of Maximum Range and Stripped Empty Weight Based on Minimum Feasible Empty Weight/Gross Weight Ratios
Various Tip-Mounted Power Plant Configurations

Item	Tip-Mounted Rocket				Ram Jet		Pulse Jet		Ram Rocket TSFC = 12	
	Tip Speed = 650 fps $\sigma = .030$		Tip Speed = 750 fps $\sigma = .018$							
Gross Weight	350	500	350	500	350	500	350	500	350	500
EW/GW (No Tanks)	.172	.172	.172	.172	.234	.234	.252	.252	.185	.185
Useful Load	290	414	290	414	268	383	262	374	285	407
UL - 225 (Fuel + Tanks)	65	189	65	189	43	158	37	149	60	182
Fuel - Pounds*	58.5	170	58.5	170	41	150	35	142	54	164
Average GW	321	415	321	415	330	425	332	429	323	418
Fuel Rate (Lb/N Mile)	6.6	7.6	5.6	6.5	4.2	5.1	3.8	4.5	4.1	5.1
Range - N Miles	8.9	22.4	10.4	26.2	9.8	29.4	9.2	31.6	13.2	32.2
Empty Weight (No Tanks)	60	86	60	86	82	117	88	126	65	93

* NOTE: Tanks are assumed to weigh 0.1 pound per pound of the monopropellant fuel and 0.05 pound per pound of fuel for ram jet or pulse jet.

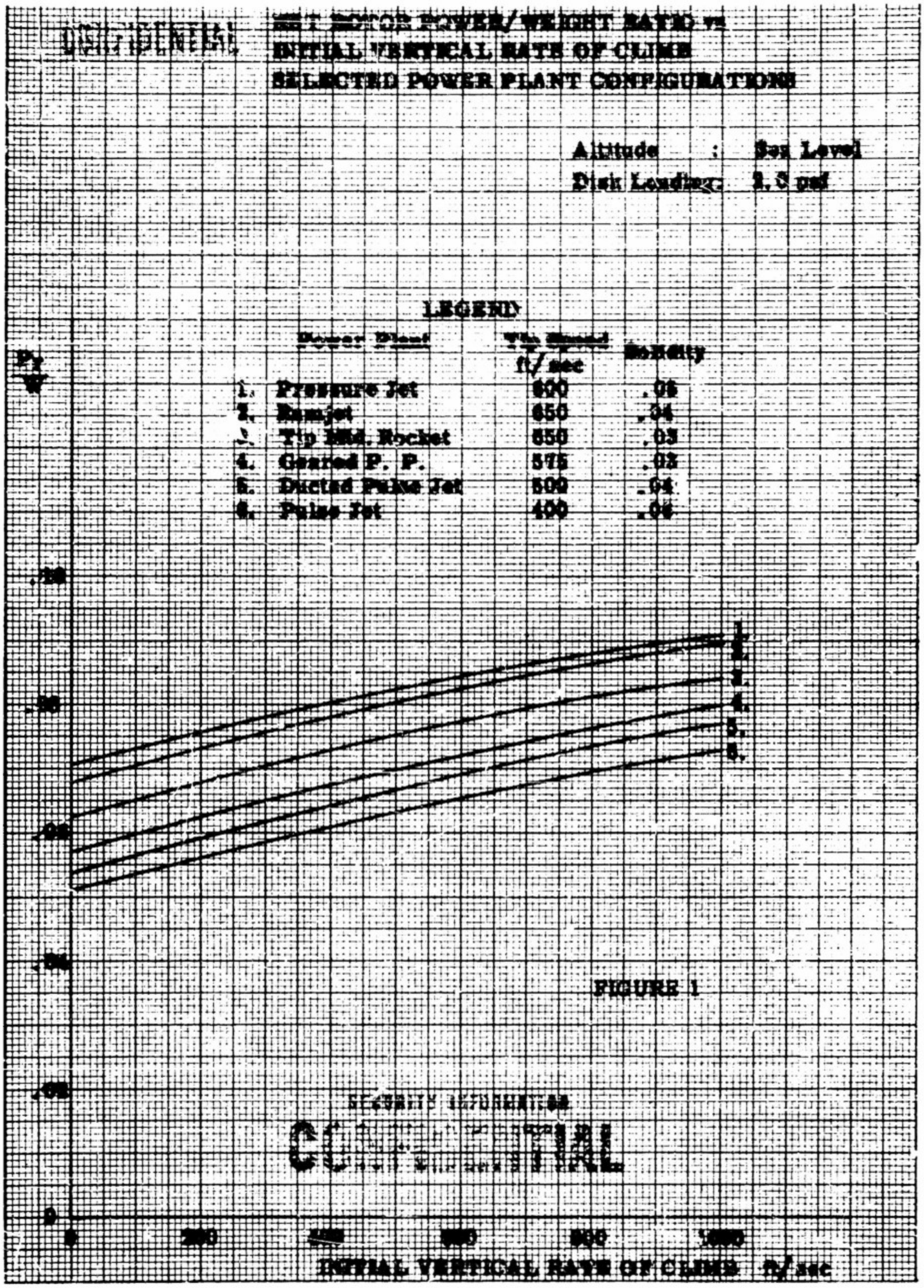
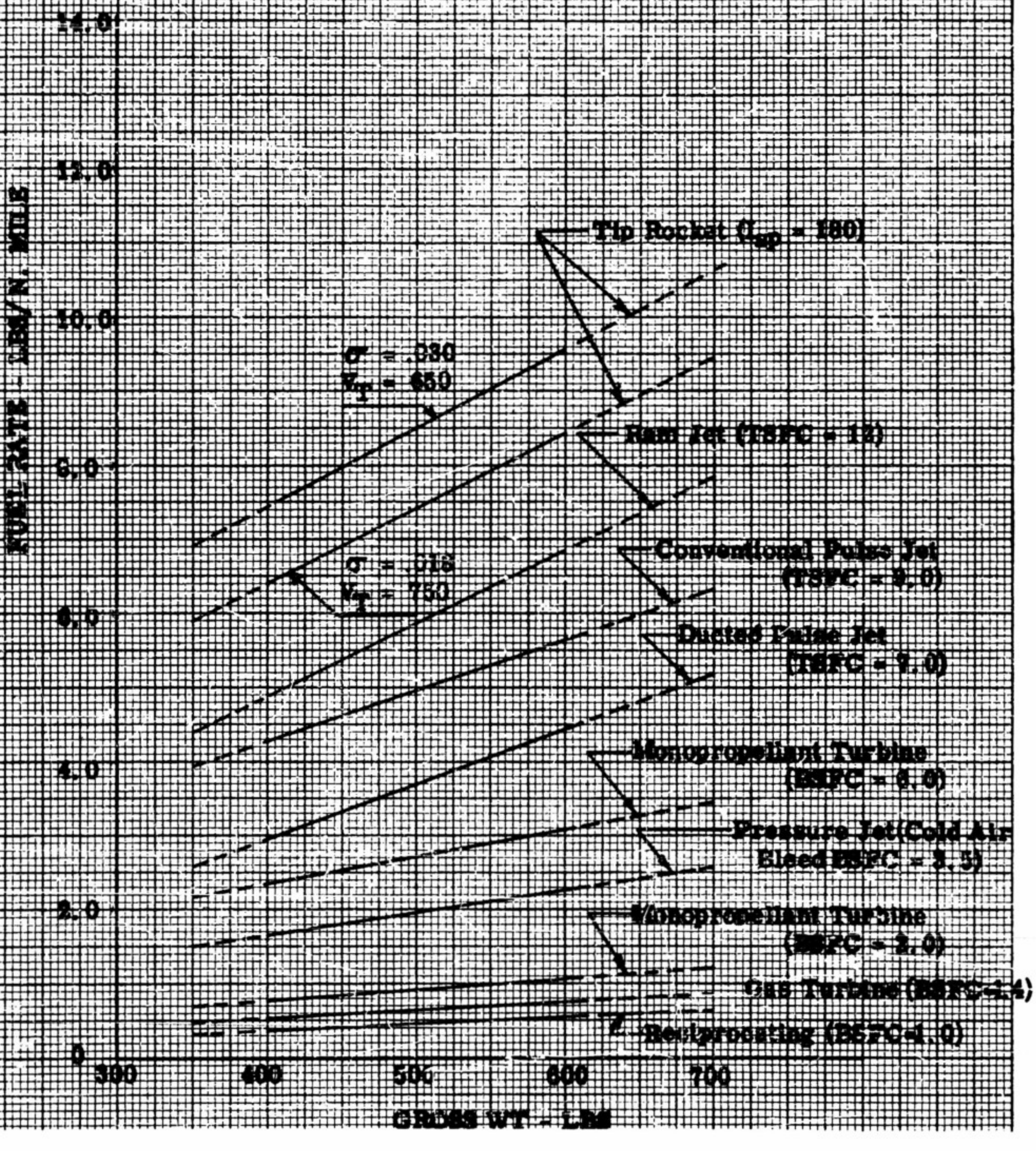

CONFIDENTIAL
NET ROTOR POWER/WEIGHT RATIO vs
INITIAL VERTICAL RATE OF CLIMB
SELECTED POWER PLANT CONFIGURATIONS
Altitude : Sea Level
Disk Loading: 2.5 psf
LEGEND
Power Plant
Tip Speed ft/sec
Solidity
1. Pressure Jet 600 .06
2. Ramjet 650 .04
3. Tip Mtd. Rocket 650 .03
4. Geared P. P. 575 .03
5. Ducted Pulse Jet 500 .04
6. Pulse Jet 400 .06
Pr/W
.10
.08
.06
.04
.02
0
0
200
400
600
800
1000
INITIAL VERTICAL RATE OF CLIMB ft/sec
1.
2.
3.
4.
5.
6.
SECURITY INFORMATION
CONFIDENTIAL

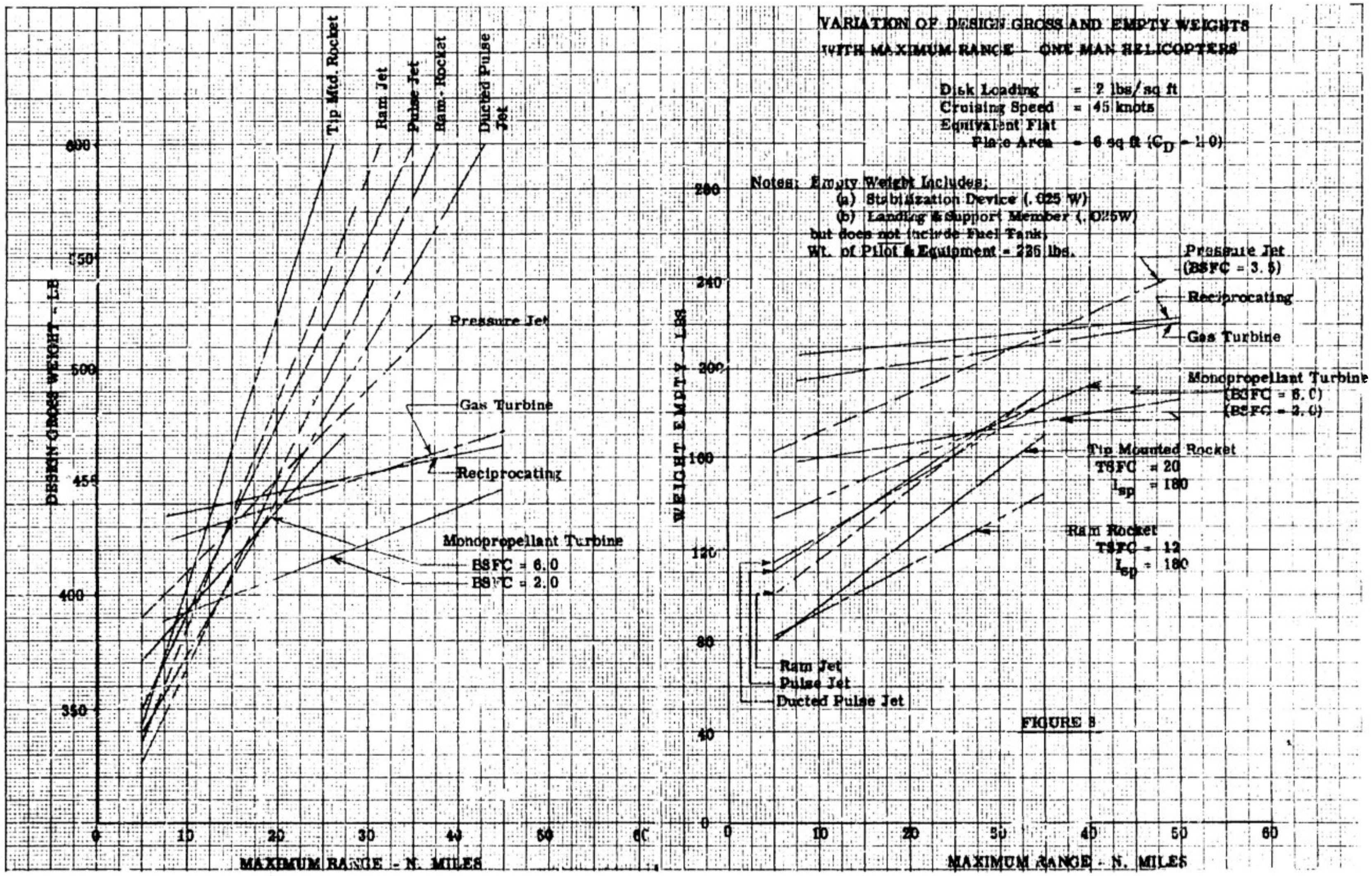
FIGURE 1

CONFIDENTIAL

FUEL RATE (in LBS/N. MILE) vs GROSS WT.
FOR MIDGET HELICOPTERS HAVING SELECTED
POWER PLANT CONFIGURATIONS

FIGURE 2



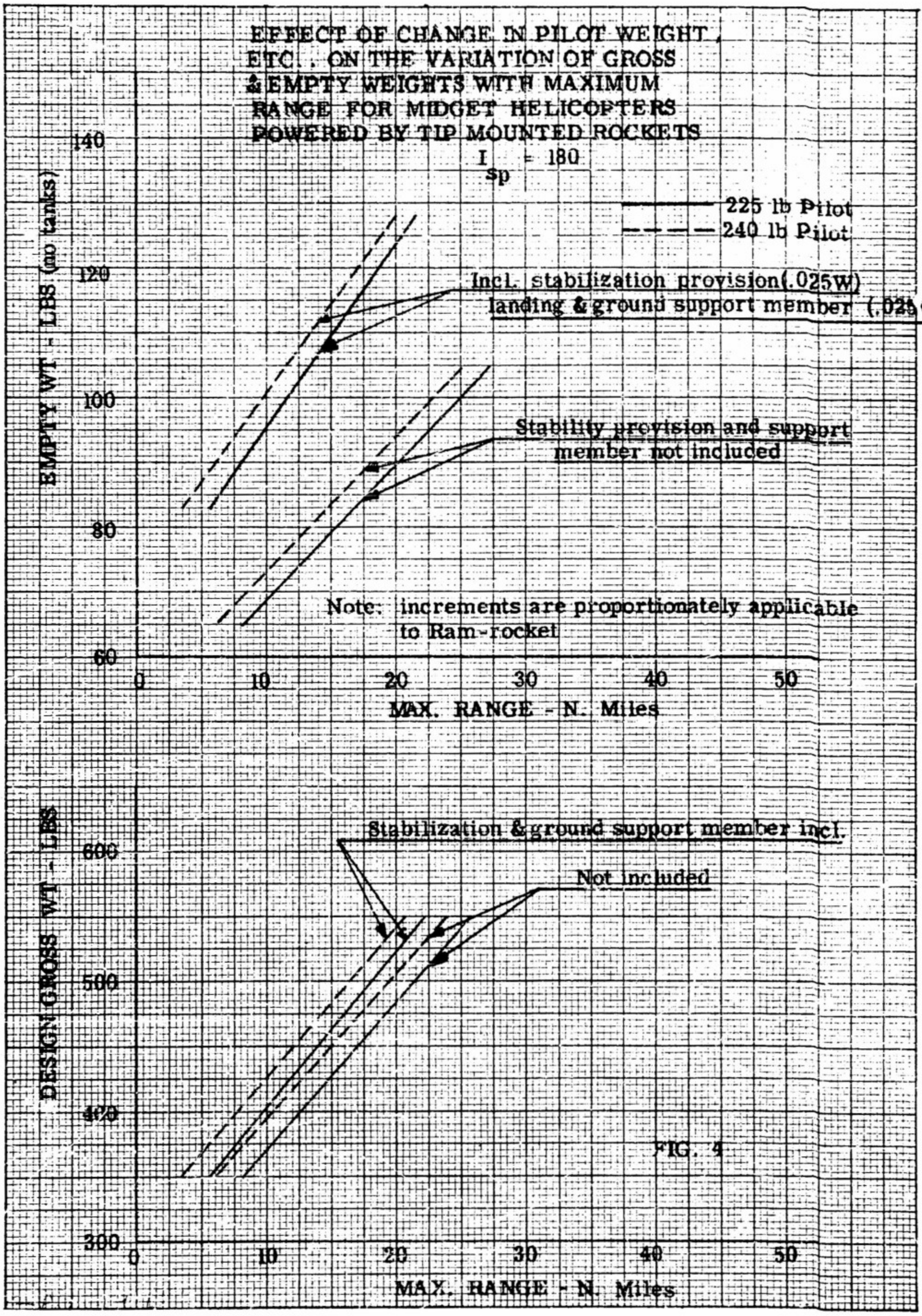


VARIATION OF DESIGN GROSS AND EMPTY WEIGHTS WITH MAXIMUM RANGE – ONE MAN HELICOPTERS

Disk Loading = 2 lbs/sq ft
Cruising Speed = 45 knots
Equivalent Flat Plate Area = 6 sq ft (C_D = 1.0)

Notes: Empty Weight Includes;
(a) Stabilization Device (.025 W)
(b) Landing & Support Member (.025W)
but does not include Fuel Tank,
Wt. of Pilot & Equipment = 226 lbs.

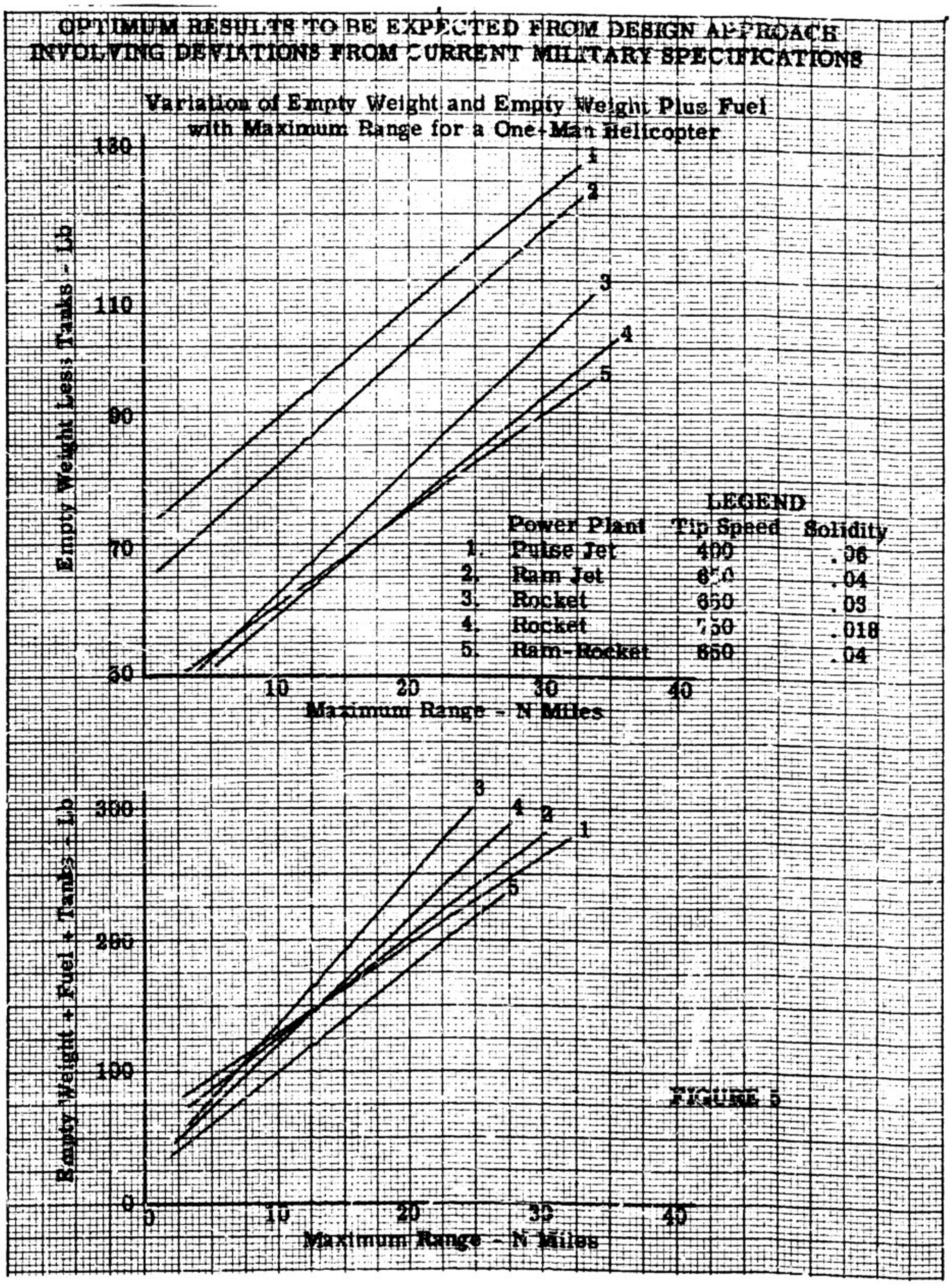
FIGURE 8



EFFECT OF CHANGE IN PILOT WEIGHT, ETC., ON THE VARIATION OF GROSS & EMPTY WEIGHTS WITH MAXIMUM RANGE FOR MIDGET HELICOPTERS POWERED BY TIP MOUNTED ROCKETS

$I_{sp} = 180$

FIG. 4



OPTIMUM RESULTS TO BE EXPECTED FROM DESIGN APPROACH INVOLVING DEVIATIONS FROM CURRENT MILITARY SPECIFICATIONS

Variation of Empty Weight and Empty Weight Plus Fuel with Maximum Range for a One-Man Helicopter

FIGURE 5

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