NASA Contractor Report 159089

NASA-CR-159089

19790019963

SENSITIVITY STUDY FOR A REMOTELY PILOTED MICROWAVE-POWERED SAILPLANE USED AS A HIGH-ALTITUDE OBSERVATION PLATFORM

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CONTRACT NAS1-13500
June 1979

NASA
National Aeronautics and
Space Administration

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SUMMARY

A study has been conducted to determine the sensitivity of several performance characteristics of a proposed design for a microwave-powered, remotely piloted, high-altitude sailplane to changes in independently varied design parameters. Results were expressed as variations from baseline values of range, final climb altitude and onboard storage of radiated energy. Calculated range decreased with increases in either gross weight or parasite drag coefficient; it also decreased with decreases in lift coefficient, propeller efficiency, or microwave beam density. The sensitivity trends for range and final climb altitude were very similar. The sensitivity trends for stored energy were reversed from those for range, except for decreasing microwave beam density. Some study results for single parameter variations were combined to estimate the effect of the simultaneous variation of several parameters: for two parameters, this appeared to give reasonably accurate results.

INTRODUCTION

A feasibility study, reported in reference 1, resulted in a microwave-powered sailplane configuration capable of performing a high-altitude, extended-duration mission. The mission profile consists of a towed take-off and climb to at least 3.05 km (10 000 ft) altitude, after which the sailplane is released within the influence of a microwave ground station to climb to the initial on-course altitude of 15.24 km (50 000 ft). From this point the mission is composed of repeated cycles of a powered climb followed by an unpowered glide to the next station.

Depending on its distance from the microwave station during climb, the sailplane's rectenna (ref. 1) receives energy which is less than, equal to, or greater than that needed to develop the full power of the propulsion motors. During those times when it is receiving more power than that required for propulsion, the excess energy is stored in batteries. The stored energy is then available to operate the payload and aerodynamic control surfaces. At no time is it used as a supplemental energy source for propulsion.

The purpose of this report is to present the results of a follow-on study conducted to determine the configuration performance sensitivity to variations in gross weight, parasite drag, operating lift coefficient, propeller efficiency, and microwave beam density. Performance items considered in this study are: range between microwave stations for determining station spacing; maximum climb altitude; and kilowatt-hours of energy received by the sailplane's rectenna system in excess of propulsion requirements.

The performance of a microwave-powered vehicle is unique for a powered aircraft in that no consumable fuel is involved; therefore, gross weight is constant throughout the flight. In addition, the fact that power available is a function of the distance between the sailplane and a fixed ground source is a limitation which has no counterpart for conventional propulsion systems.

SYMBOLS

Where applicable, values are given in this report in both International System of Units (SI) and U.S. Customary Units. All calculations were made in U.S. Customary Units.

C_L	lift-coefficient, Lift/qS
C_{D_p}	parasite drag coefficient
L/D	lift-drag ratio
R_e	Reynolds number
q	dynamic pressure
S	reference wing area
η_p	propeller efficiency

BASELINE CONFIGURATION

Configuration Summary

The microwave-powered sailplane configuration (ref. 1) is shown in figure 1. The significant physical details of the sailplane are a wing aspect ratio of 30, a projected wing area of 111.5 m^2 (1 200 ft^2), and two 67 kw (90 HP) direct-current electric motors each driving a 7.32 m (24 ft) diameter three-blade propeller.

Performance Summary

The baseline performance values were computed in the study of reference 1. These include a range between microwave stations of 432 km (233 n mi), a peak altitude of 23.26 km (76 300 ft), stored energy of six kilowatt-hours per cycle, a gross weight of 15.57 kN (3 500 lbf) with a payload of 4.89 kN (1 100 lbf), and a constant lift coefficient of 0.9 throughout the flight. The values of C_{D_p}, η_p, and the microwave beam density are represented by curves, or families of curves, developed during the study of reference 1. The mission profile is presented in figure 2 (ref. 1) and represents the capability of the baseline configuration.

RESULTS AND DISCUSSION

Parameters

The following parameters were varied in this study: gross weight, parasite drag coefficient, lift coefficient, propeller efficiency, and microwave density. One parameter was varied at a time except in the light gross weight cases (i.e., baseline gross weight reduced by approximately 15 to 25 percent). In order to maintain reasonably high propeller efficiencies at the flight conditions for the lighter weights, higher propeller speeds were required. The effect on range of not being able to fold the propeller blades was also determined. Only range is affected since the propellers are folded only after the climb phase is completed.

Range Sensitivity

Range between microwave stations is a function of both the altitude achieved during the powered phase and the lift-to-drag ratio L/D developed in the glide segment. Parameters which increase the rate-of-climb or L/D contribute to an increase in range. Although increasing the lift coefficient appears to be beneficial because the average flight L/D is improved, the increase may have other effects. Maximum lift coefficients decrease with decreasing Reynolds numbers R_e , as indicated in reference 2. Since C_L is held constant throughout the flight, an increase in C_L requires a reduction in velocity, resulting in a lower Reynolds number. The combination of increased lift coefficient and reduced Reynolds number may result in stall. Significant increases in either microwave beam density or propeller efficiency were not considered to be reasonable expectations; thus, only reductions in these parameters were studied. The effect of variations in gross weight and parasite drag coefficient were determined over a wide range of parameter values. The resulting range sensitivities are shown in figure 3. The percentage range changes are measured from the baseline value of 432 km (233 n mi). Figure 3 includes the range loss due to gliding with unstowed but feathered propellers (indicated by the small circle).

Analysis of figure 3 shows that for the same percentage change in each parameter, the range penalty for reduced η_p is greater than it is for lower beam density. This difference occurs because each of these parameters has a different effect on thrust horsepower. Lowering η_p results in less thrust horsepower at all flight conditions; however, it is still possible to develop the full rated power of the electric motors through a significant portion of the climb even with a 10 to 15 percent reduction in beam density.

Final Climb Altitude Sensitivity

The final climb altitude sensitivities are similar to those for the range variation and are presented in figure 4. All parameters causing reductions in rate-of-climb (such as reduced microwave power or propeller efficiencies, higher weights or drag, and lower L/D associated with lower than baseline lift coefficients) result in lower final altitudes. Increased final altitudes are achieved when rates-of-climb are increased by reducing either weight or drag or by increasing C_L.

Excess Energy Sensitivity

The level of energy available from storage in the sailplane batteries was also affected by parameter variation. Excess energy is defined as the result of timewise integration of power, received by the rectenna system, that exceeds the level needed for propulsion. Parameter variation effects are presented in figure 5.

In all cases except for the microwave beam density, the effect of the various parameters on stored energy is opposite to the corresponding effect on range. Items which increased range reduced the stored energy while those parameters which decreased range led to greater excess energy for storage. This relationship between range and excess energy exists because these performance items are affected in opposite ways by the rate-of-climb which controls the climb altitude. Range increases with higher climb altitudes, but energy received by the vehicle varies inversely with distance from the ground station. A reduction in the microwave beam density resulted in not only a lower final climb altitude and thus shorter range, but also a greatly diminished excess wattage. The proximity of the sailplane to the microwave station during the climb was found to be the principal determinant of the magnitude of the excess kilowatt-hours.

Combination of Parameters

An additional analysis was undertaken to establish whether the effect on performance of varying more than one parameter simultaneously could be determined from the independent effects shown in figures 3, 4, and 5. The results of this analysis indicated that sensitivities obtained from the figures for combinations of two parameters were very accurate in nearly all cases when compared to the computed values for such combinations. For example, from figure 3 changes of -12.5 percent in C_{D_p} and -8.57 percent in gross weight result in range increases of 6.8 and 9.3 percent, respectively. Multiplying the range increases (1.068 x 1.093) produces an indicated range increase of

16.7 percent compared with a computed combined-effect range increase of 17.4 percent. The excess kilowatt-hours parameters (fig. 5) may be combined in the same way.

The effect of combined parameters on final climb altitudes (fig. 4) is determined in a different manner since the final climb altitudes are presented in absolute terms rather than percentages. To illustrate, entering figure 4 with parameter changes of -12.5 percent in C_{D_p} and -8.57 percent in gross weight produces altitudes of 23.35 km (76 600 ft) and 24.18 km (79 330 ft), respectively. Subtracting the baseline value of 23.26 km (76 300 ft) from each of the above altitudes results in incremental altitudes of 0.09 km (300 ft) and 0.92 km (3 020 ft), respectively. Adding the increments to each other and then to the baseline yields an indicated final climb altitude of 24.27 km (79 620 ft) compared with a calculated combined-effect value of 24.31 km (79 760 ft). When η_p was one of the parameters considered, the accuracy diminished slightly. If three parameters were considered simultaneously, the results were significantly less accurate.

CONCLUSIONS

A study has been conducted to determine range, final climb altitude, and energy storage sensitivities of a microwave-powered, remotely piloted high-altitude sailplane to changes in gross weight, parasite drag and lift coefficients, propeller efficiency, and microwave beam density. Each parameter was varied independently relative to previously determined baseline values. The results of the study show that:

1. Range between microwave ground stations increases when the gross weight or parasite drag coefficient is decreased or when the lift coefficient, propeller efficiency, or microwave beam density is increased. Gliding with feathered propellers, rather than folded propellers, reduces range.

2. The sensitivity trends for final climb altitude were very similar to those for range.

3. In all cases except for the microwave beam density, the effect of the various parameters on stored energy is opposite to the corresponding effect on range.

4. Sample calculations show that the effects of independent parameter changes may be combined to yield satisfactory estimates of the combined effect of varying two parameters simultaneously. Lesser accuracy is obtained for combined changes in three parameters.

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1. Heyson, Harry H.: Initial Feasibility Study of a Microwave-Powered Sailplane as a High-Altitude Observation Platform. NASA Technical Memorandum 78809, December 1978.

2. Abbott, Ira H.; von Doenhoff, Albert E.; and Stivers, Louis S., Jr.: Summary of Airfoil Data. NACA Report 824, 1945.

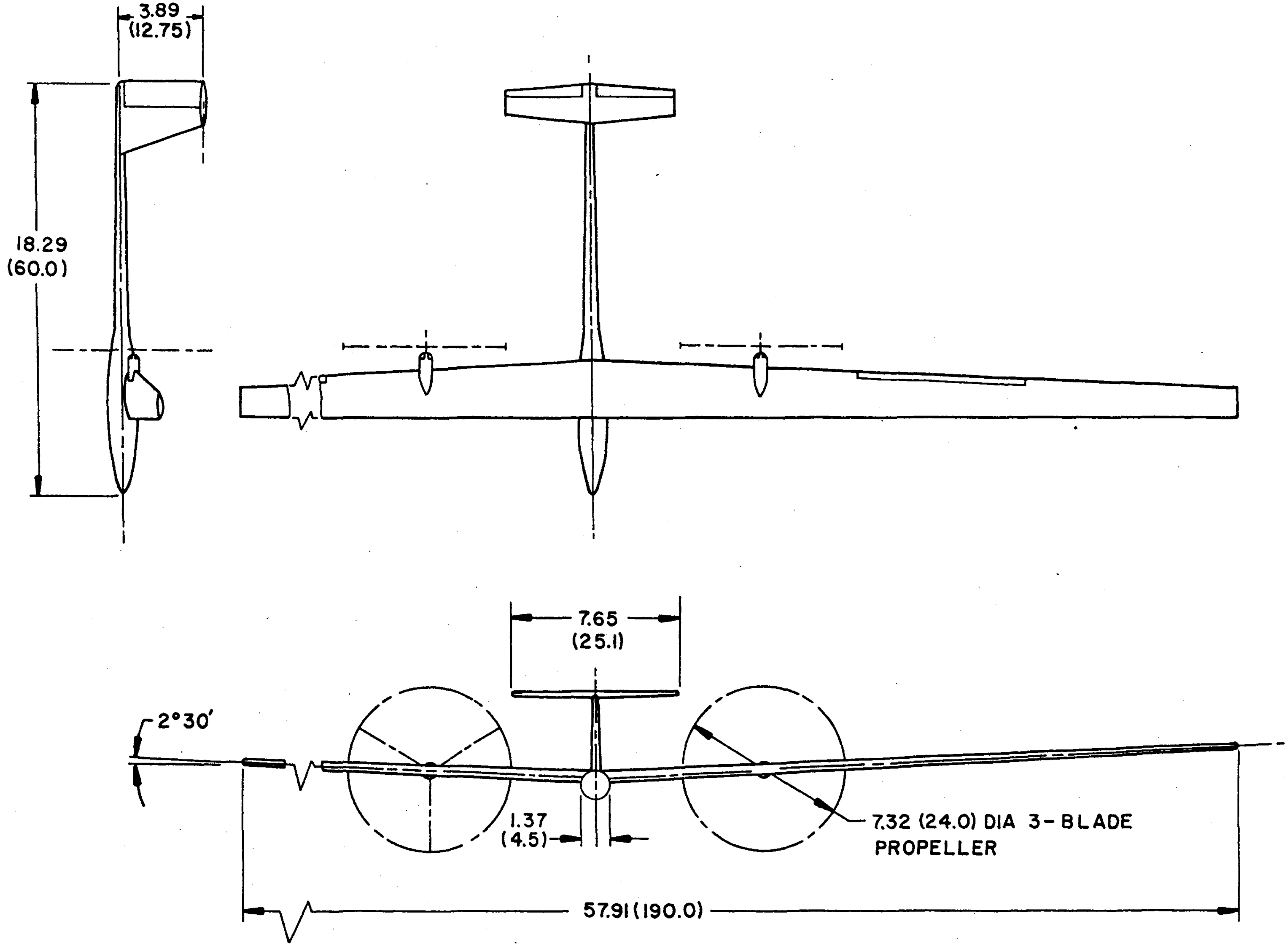

Figure 1.- Geometric characteristics of the microwave-powered aircraft. Dimensions are in meters (feet).

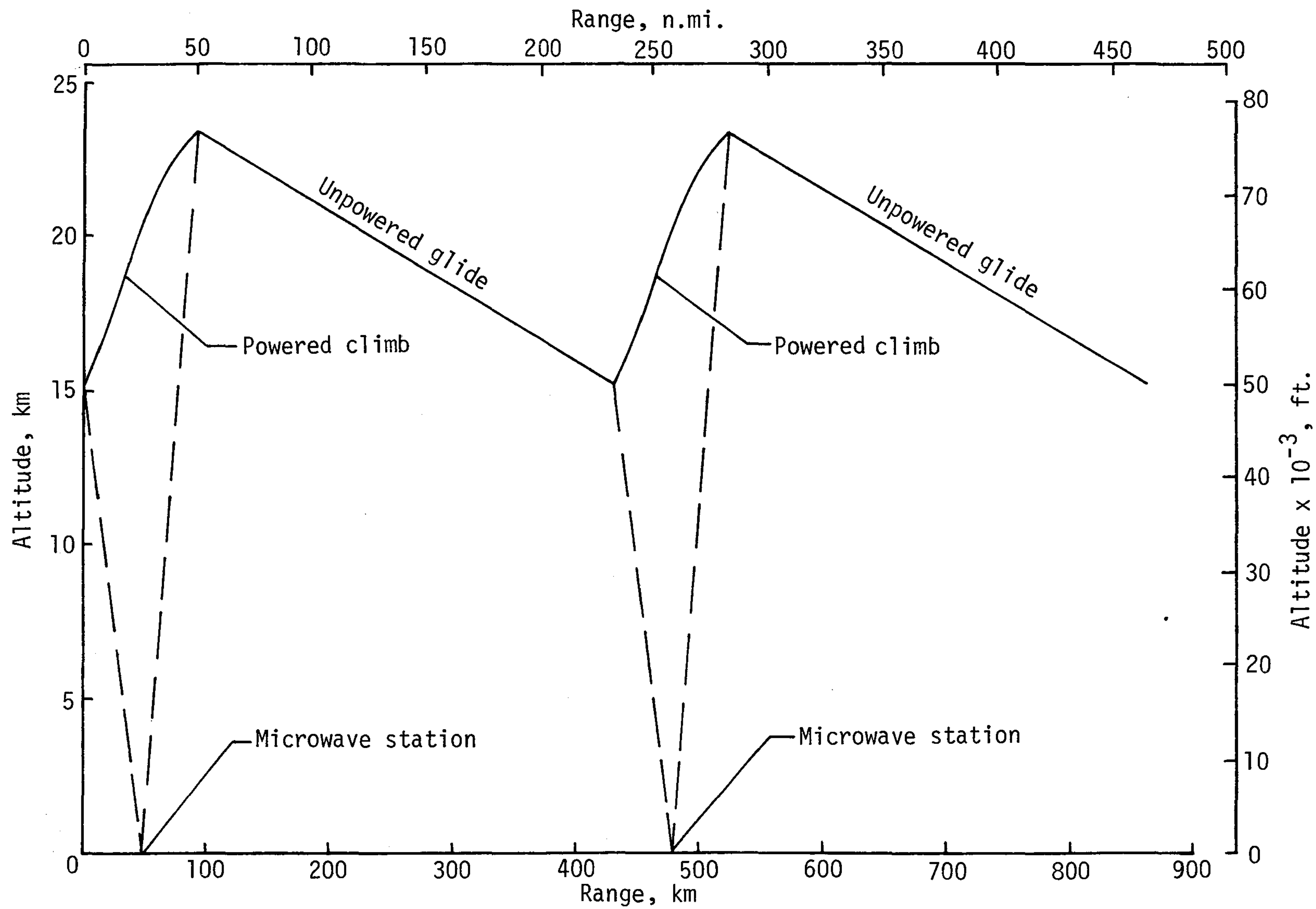

Figure 2. - Baseline mission performance capability for this study as a function of distance from the start of the climb segment.

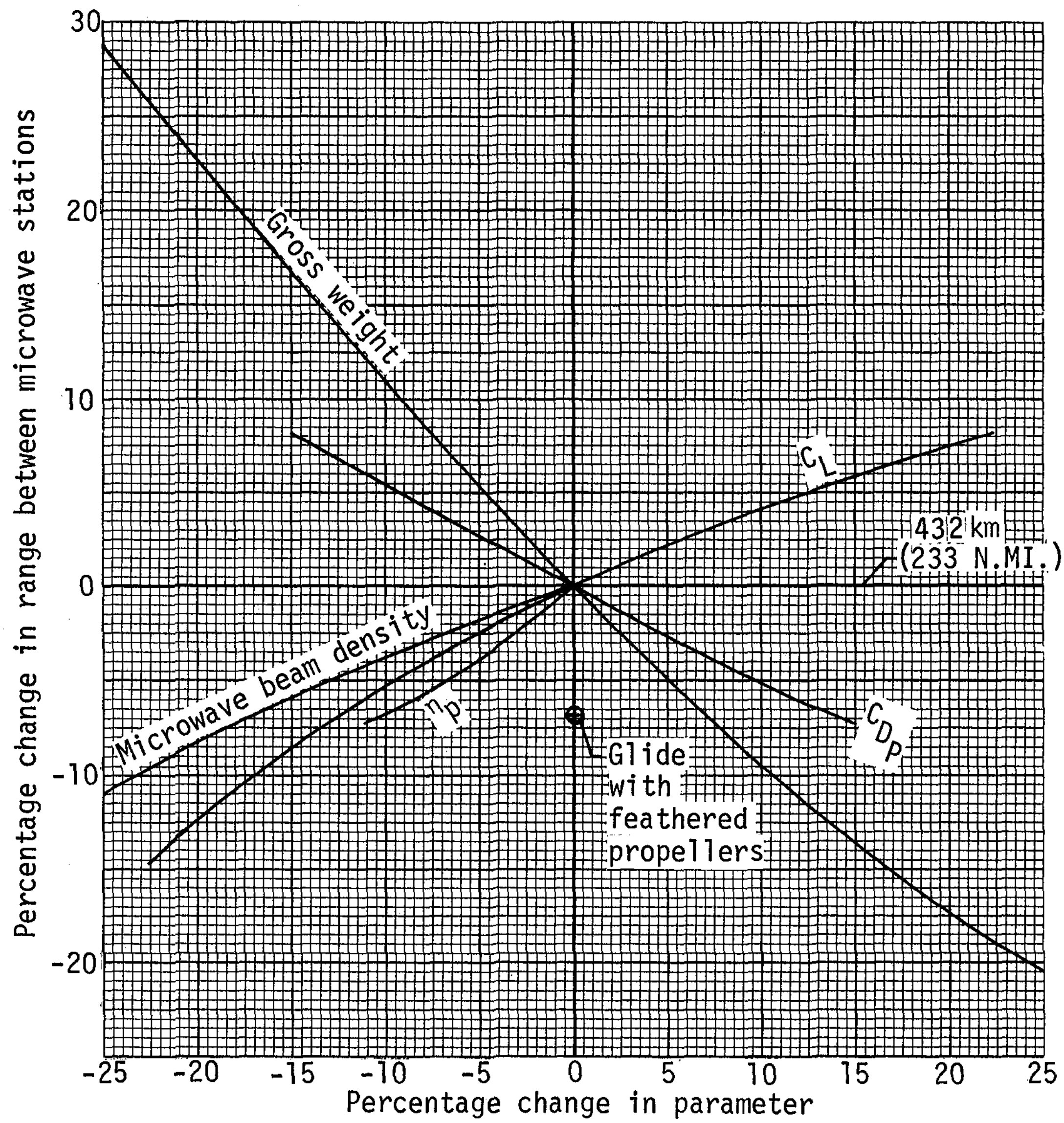

Figure 3. - Effect of various parameters on the range between microwave stations.

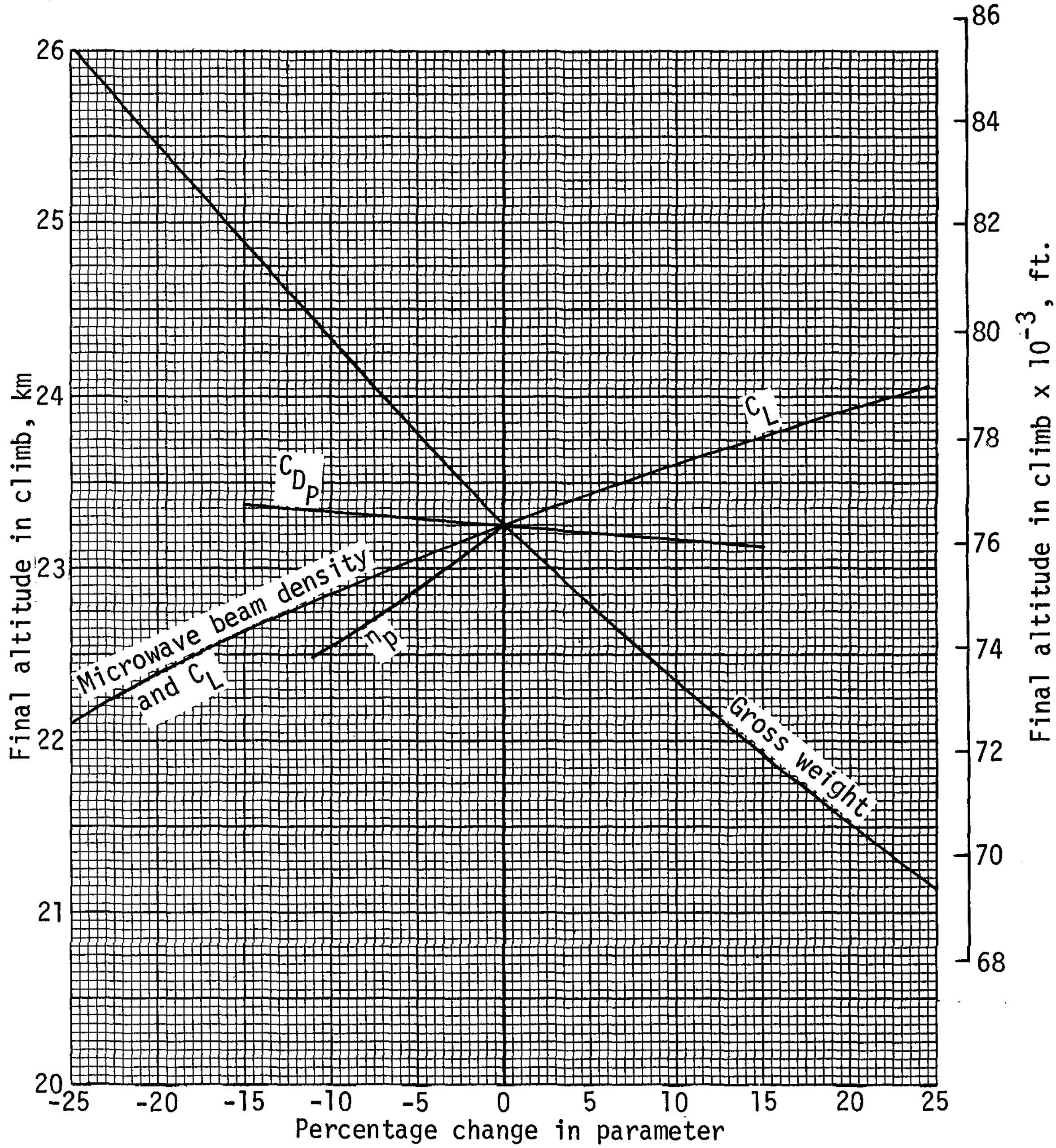

Figure 4. - Effect of various parameters on the final climb altitude.

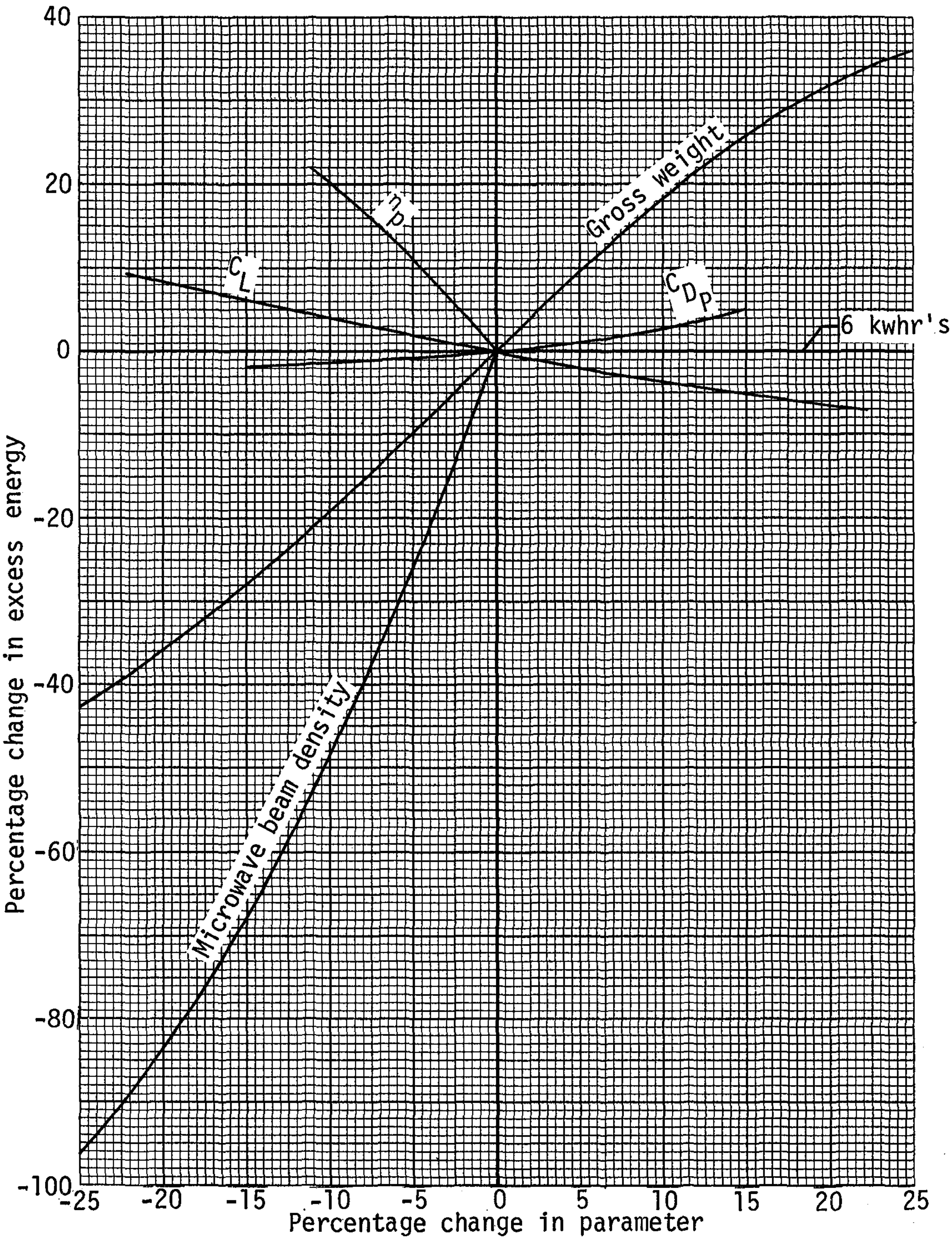

Figure 5. - Effect of various parameters on energy received in excess of propulsion requirements.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-159089		

4. Title and Subtitle	5. Report Date
SENSITIVITY STUDY FOR A REMOTELY PILOTED MICROWAVE-POWERED SAILPLANE USED AS A HIGH-ALTITUDE OBSERVATION PLATFORM	June 1979
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
R. Victor Turriziani	
9. Performing Organization Name and Address	10. Work Unit No.
Kentron International, Inc., Hampton Technical Center 3211 North Armistead Avenue Hampton, VA 23666	791-40-43-01
	11. Contract or Grant No. NAS1-13500
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
National Aeronautics and Space Administration Washington, DC 20546	Contractor Report
	14. Army Project No.

15. Supplementary Notes

Langley Technical Monitor: Charles E. K. Morris, Jr.

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17. Key Words (Suggested by Author(s))	18. Distribution Statement
Microwave power High altitude observation Sailplanes	Unclassified - Unlimited STAR Category-02: Aerodynamics

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	13	$4.00

*For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-Langley, 1979