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FLIGHT ACCURACY STUDY OF GLIDE-OUT ANCHOR

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FLIGHT ACCURACY STUDY OF GLIDE-OUT ANCHOR

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13. ABSTRACT

This document covers the work performed during a study made of the Glide-Out Anchor to improve the glide accuracy of its present design. Wind tunnel testing and model analysis was employed in the program study.

Analysis of the results indicate that the anchor can be successfully improved in all design areas under investigation.

To further develop the Glide-Out Anchor, and to verify the results of this study, an in-water test program will be necessary.

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FOREWORD

This report covers the work performed under Contract N62399-72-C-0003 *Flight Accuracy Study of Glide-Out Anchor*, which includes wind-tunnel testing and model analysis.

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A. SUMMARY

Utilizing wind-tunnel testing and model analysis, a study program was conducted to improve the flight accuracy of a Glide-Out Anchor (see Figure 1). The study was mainly concerned with two areas: 1) reducing the sensitivity of the GOA to cross currents, and 2) reducing the steepness of its average glide angle.

The results of the study indicate that not only can the anchor be sucessfully improved in both these areas, but that the basic configuration is quite stable and can be successfully adapted to a wide range of applications.

A wood and aluminum wind-tunnel model was designed, fabricated, and tested in an 8-by-12-foot wind tunnel, located at the University of Washington. Variations in wing dihedral angle, wing shape, stabilizer shape and position, and drag cone size were tested. The test results were analyzed, and a preliminary configuration was selected from those evaluated which would best meet the design goals of the study.

Results of the wind tunnel tests and analysis indicate that the unexplained azimuth deviations measured during testing of a ten-inch long Glide-Out Anchor are not due to the basic Anchor design, but are a result of launch errors introduced by our present launcher system. Utilizing different drag cones, the wind tunnel tests have shown that the basic anchor can be successfully configured with a smaller drag cone, and its glide angle reduced from 45 to 30 degrees, from the horizon, with no loss in flight accuracy.

Further in-water model testing will be necessary to validate the results of this study and to develop an optimum configuration.

B. BACKGROUND

The Glide-Out Anchor (GOA) (Figure 1) is a hydrodynamically stable shape, which, when launched in water, will glide along a straight path until it reaches the ocean bottom. The body is propelled by its own weight and attains the desired glide angle and stability through a combination of wings, horizontal stabilizers, and a drag cone. It is completely passive, requiring no other control or propulsion system.

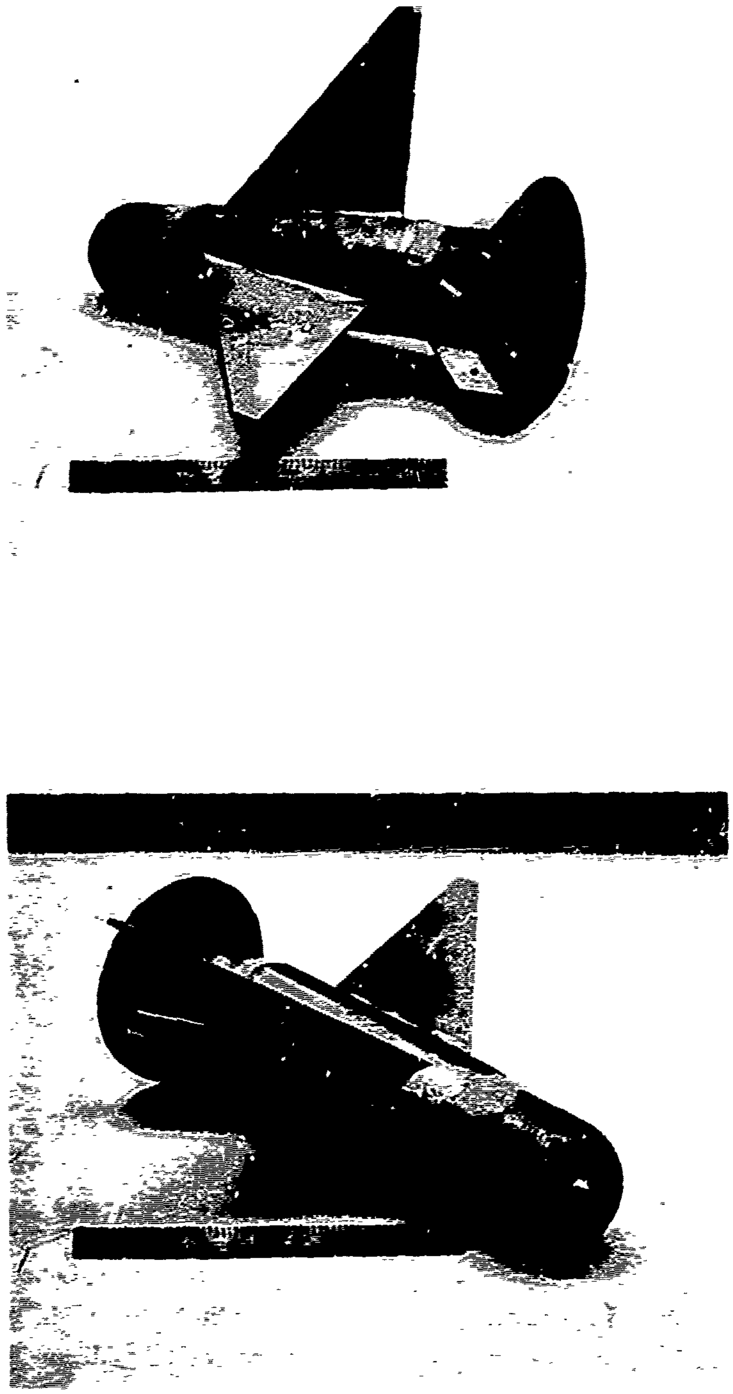


Figure 1. Glide Out Anchor

The concept was originally developed to allow rapid and automatic implantment of three-point reference mooring. The GOA is potentially useful whenever items such as anchors, instruments, etc., are to be spread in a pattern on the sea floor. It allows several units to be launched at once from a single point, which can reduce implantment time, cost, and risk. The operation can be carried out more covertly and in some cases with greater relative accuracy than is possible with conventional lowering or free-fall implantment techniques.

The Glide-Out Anchor concept and body shape were developed independently by Honeywell, using a combination of wind tunnel testing, analysis, and in-water testing. During this initial development, GOA's were used to successfully deploy synthetic mooring lines, up to 1/8 inch in diameter, in water depths from 30 to 2,000 feet. Later testing, performed during a preliminary study for the Navy, demonstrated the ability of the anchor to deploy metallic lines in 600 feet of water. However, two problem areas were found: 1) the azimuthal deviation of the anchor in a cross current was larger than could be attributed to drift alone, and 2) the average glide path of the anchor to the bottom was steeper than desired. The present contract (*Flight Accuracy Study of Glide-Out Anchor*) was then funded by the Naval Civil Engineering Laboratory (NCEL) to develop an improved anchor configuration in these two areas.

C. STUDY OBJECTIVES

There were two distinct study objectives: 1) To investigate the causes of the large azimuthal divergence, measured in previous water tests, and 2) to develop an anchor that would glide to the sea floor at a shallower angle than the 45 degrees of the present anchor model.

During a previous unpublished study, azimuthal divergences were recorded that could not be attributed to drift alone. A goal of this present study was to develop an anchor that would maintain a ±5 degree accuracy over that error caused by normal drift from the original launch heading.

The second objective, to develop a shallower glide angle, came about as a result of the same previous study described above, where the resulting average glide angle, while deploying wire cables, was steeper than desired.

The objective of this second part of the present study was, therefore, to prove that the present Glide-Out Anchor design could be modified to glide at shallower glide angles, ranging from 30 to the present 45 degrees from the horizontal.

Once this ability to glide at the desired range of angles is proven, an additional study can be undertaken to determine the exact effect the wire cable imposes on the glide path of the Glide-Out Anchor.

D. STUDY PLAN

To accomplish the objectives of the study, a three-phase plan was set up.

First, a preliminary design would be developed, based upon previous experience with the Glide-Out Anchor, and would show where the necessary data was not available.

Second, a test program would be conducted which would include the design and fabrication of a wind-tunnel model, based upon the preliminary design. A test matrix would also be planned to fill in the gaps in the aerodynamic data and to provide a body of data for future design.

Third, the data compiled from the wind-tunnel tests would be used to perform an analysis of the preliminary design to decide on any necessary changes to the final configuration.

The analysis would include calculation of the performance of the preliminary design, both in the areas of glide angle and stability. In the area of longitudinal stability, the effects of different tail surfaces and the center of gravity (c.g.) location would be calculated.

In the area of spiral stability, the response to disturbances and the sensitivity to launch errors would be investigated.

The object of the preliminary design effort would then be to develop a wind-tunnel model to provide data over a range of expected usefulness and to detect any problems that might be generated. The results of the study program, then, would be used to develop the final configuration.

E. PRELIMINARY DESIGN

1. Design for Performance

a. Design Selections

The gross weight of a full size anchor with a length of 100 inches is estimated to be 8500 pounds. The anchors are of solid cast iron with steel plates for the lifting surfaces. A major design goal was for as much simplicity and ruggedness as possible.

b. Design Performance

The basic glide angle should be variable within a range of 30 to 45 degrees below the horizontal.

c. Design Glide Speed

Glide speed should be as fast as possible for glide stability, and as low as possible to minimize the launch energy required to bring the anchor up to glide speed. A glide speed of 25 feet per second, full scale, was chosen for the preliminary design; this was determined to be the lowest practical speed. Faster glide speeds would ease any anchor-design stability problems.

d. Wing Design

The wing airfoil shape consists of a rectangular cross section, with a full-radius leading edge. This shape was chosen for its simplicity of construction.

(1) The lift coefficient was estimated at greater than 0.6, based upon previous glide data.

(2) The drag of the blunt section is also useful for obtaining the desired steep glide path.

(3) A lift coefficient, C_L, of 0.6 was chosen for normal glide, and results in a wing area of 19.5 square feet.

(4) A body attitude parallel to the glide path was chosen which required a calculated incidence angle of about 10 degrees.

(5) Two wing plan forms were chosen for investigation. The swept back (delta) shape was chosen, due to its favorable effect on C_L maximum when used with low-aspect-ratio wings. Low-aspect-ratio wings were chosen because of high drag desired. The straight wing was selected for its simplicity of construction.

(6) The wing was raised from its mid-body position (used in previous tests) to the top of the body for ease of construction, and to free the main body for increased payload which might be required for future applications.

c. Body and Drag Cone Design

A simple body shape with a spherical nose was maintained from previous design to provide a smooth entry, thus preventing an unsteady wake on the wing and tail.

(1) The body diameter of 20 inches and a length of 100 inches were chosen to obtain the desired weight.

(2) The length-to-diameter ratio was chosen as short as considered possible for compactness and for ease of handling. A longer vehicle would be expected to have better stability and ease design problems. The length of the body was deliberately chosen to be as short as possible, since it could be lengthened just as the glide speed could be increased during later design effort, if required.

(3) The size of the drag cone would be varied to obtain the desired glide angle. The size was selected to obtain the desired glide angle of 30 to 45 degrees, based upon the base drag coefficient, C_D, of 0.5. A 30-degree glide angle was predicted with a 40-inch diameter (full-scale) drag cone, and a 45-degree glide angle was expected with a 56-inch diameter drag cone.

2. Design for Stability

a. Longitudinal Stability

Tail sizes were chosen for a contribution to longitudinal stability and were based on use of similar surfaces in previous experiments.

Analysis is difficult, because of the interference effect of the drag cone on the flow over the tail and the unpredictable contribution of the cone itself. Downwash from the wing was expected to greatly reduce the tail influence; in fact, the principal stability effect was expected to come from the cone, and the presence of the tail surfaces was intended to make the cone more effective.

Since the stability was so unpredictable, it was decided to place the wing aerodynamic center on the center of gravity for neutral wing contribution, and adjust the wing position later, as required. Since no evidence was available as to the required static margin for this type of vehicle, the results of the wind tests would be used to select the final design.

b. Spiral Stability

No real attempt was made to predict the spiral stability of the GOA in this phase. It is well known that a rather large ratio of dihedral effect to directional stability improves spiral stability, but that too much leads to an oscillatory instability called the Dutch roll.

A vertical fin was placed on the bottom of the body to be in a region unaffected by the wing.

The dihedral required was completely unknown, and no attempt was made to predict it beforehand. Experience with the 30-degree dihedral on earlier gliders, and the resultant lateral deviations measured during testing, suggested that the sensitivity to cross currents might have been due to excessive dihedral. Therefore, the wind-tunnel program was planned to have two different dihedral angles which would allow the measurement of dihedral effect. Analysis of any spiral stability was postponed until the data from the wind-tunnel test was available.

F. TEST PROGRAM

The test program was planned with the objective of collecting data over a range of adjustments of the model component sizes and shapes which would permit better design of a later vehicle.

1. Model Scaling

The model scaling and speed of the tests were chosen to match, as nearly as possible, the full scale Reynolds number of the vehicle in operation. The Reynolds number of the GOA in operation for a body length of 100 inches at a speed of 25 feet per second is about 16×10^6. The Reynolds number for the wing, based on a chord length of 28 inches is about 4×10^6.

The wind tunnel Reynolds number, in air, was limited by the test speed that could be reached without overloading the drag balance of the wind tunnel. For a model having a body length of about 50 inches, tested at an air speed of 125 miles per hour, the test Reynolds number is about 5.2×10^6; and for a wing chord of 13.7 inches, the Reynolds number is about 1.7×10^6. These values are sufficiently high that extrapolation to full scale is considered reliable.

The effect of the Reynolds numbers on maximum lift coefficient was expected to be important, and plans were formulated to test only the wing-body combination at higher speeds than could be performed with the tail cone attached to measure the effect. A maximum Reynolds number of 2.7×10^6 was expected to be measured.

The testing of the effects of cross currents was achieved by running the model at various yaw angles (ψ). A four knot cross-current, acting on a vehicle flying at 25 feet per second, results in an equivalent of 15 degrees of yaw. The tests were performed at angles up to ±30 degrees of yaw angle.

2. Test Run Schedule

The test program was designed to answer specific questions, and to provide the data for a final design. The wind tunnel tests were necessary since many of the items of concern cannot be predicted because the configurations depart too far from normal experience. The various parameters to be determined, in the areas of interest, by the wind tunnel, are shown below.

a. Lift

- Slope of lift curves of chosen section
- Maximum value of lift coefficient
- Stall characteristics
- Scale effect on maximum lift

b. Drag Coefficient

- Body
- Cone effect on drag
- Wing section drag
- Span efficiency factor

c. Pitching Moments

- Body
- Effect of drag cones
- Downwash factors
- Effectiveness of horizontal tail in sheltered location

d. Dihedral Effects

- Effect on roll and yaw of at least two dihedral angles
- Effect of high wing position
- Effect of low vertical tail position

e. Directional Stability

- Effects of:

  Body
  Tail Cones
  Vertical Fins
  Wing Location

f. Configuration Effects

- Two wing plan forms
- Two tail cone sizes
- Two horizontal tail sizes

G. ANALYSIS

1. Selection of Configuration For Further Analysis

Nonlinear interference between the straight wing and either of the drag cones showed up in the lateral characteristics. The effect was most visible in the directional stability at small angles of yaw (less than 3 degrees) where the tail and cone reduced the stability of the body-wing combinations. At larger yaw angles they provided ample stability. When the wing was raised to 10 degrees of dihedral the interference effect disappeared, and the configuration was directionally stable. Similarly, in the rolling moment, the effect of the large cone and tail assembly on the straight wing was to de-stabilize the body for small angles of yaw. With the small cone, this effect was not present. In contrast, the delta wing did not show these non-linear interference effects, but gave reasonable linear results in the respective yawing and rolling moments and side force, with the effects of dihedral also appearing to progress in an expected way.

The pitching moment curves also displayed the same unexpected results. The curves for the delta configuration were quite linear with both large and small cones, while those for the straight-wing configuration were parabolic. Even with the tail off, the body-wing configuration was unstable at lift coefficients below 0.4 and stable above 0.4.

These non-linearities are unexplained at the present time, and make it extremely hazardous for the extrapolation, or even interpolation, of the data for the straight wing. Since the data for the delta wing is so well behaved, both in the longitudinal and lateral moments, this configuration was chosen for all further analyses.

2. Performance Analysis

In order to develop a configuration for a selected glide angle, a drag cone size and a lift coefficient to fly at are first chosen. Then, a tail and center of gravity location are selected to cause the pitching moments to be stable and to balance at the chosen lift coefficient.

An examination of the data for the delta wing configuration shows that the lift and pitching moment curves are straight, as long as the lift coefficient, C_L, is less than 0.75. Some margin of C_L is desired in case of turbulence, so a C_L of 0.6 was chosen.

The glide angle at $C_L = 0.6$ does not exactly match 30 or 45 degrees for either cone. The drag coefficient, C_D, required for a chosen glide angle is given by the following:

$C_D = C_L \tan \gamma$ where γ is the glide angle from the horizontal

The tabulation below gives the required C_D and the measured C_D for the two desired glide angles and the two drag cone sizes for flight at $C_L = 0.6$.

For α	C_D Required	C_D Measured at $C_L = 0.6$	
		Small Cone	Large Cone
30 Degrees	0.347	0.435	–
45 Degrees	0.600	–	0.790

The proper values of the cone sizes can be selected by interpolation on a plot of C_D versus cone diameter and are tabulated below.

For α	C_D Required	Cone Diameter Body Diameter	Cone Diameter Body Diameter
30 Degrees	0.347	3.0	1.7
45 Degrees	0.600	5.8	2.4

The curve in Figure 2 shows the linear nature of the base drag characteristic which allows interpolation, with some confidence, to choose any desired glide path from this data. From the curve it can be seen that a cone 1.7 times the body diameter would produce the desired 30-degree glide path. A cone of 2.4 times the body diameter will produce a 45-degree glide angle.

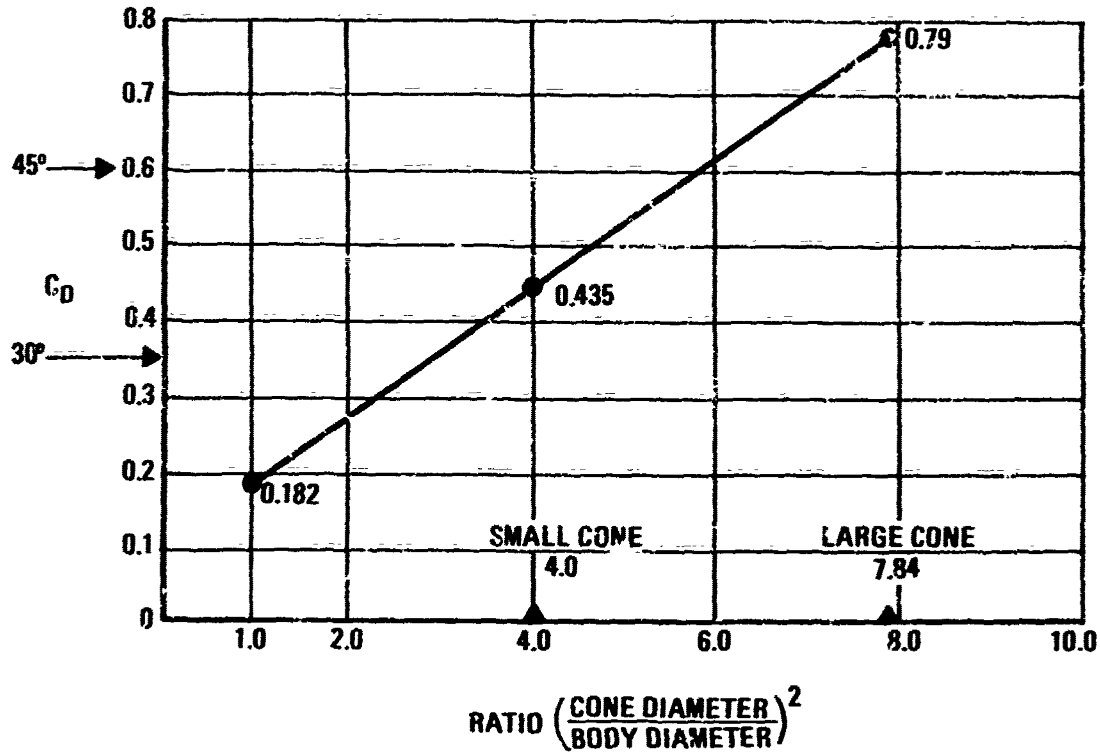


Figure 2. Base Drag Characteristics

The following sample calculation will show that the glider can be made to balance at zero moment at the desired C_L. The pitching moment curves (Figure 3) for the configurations with the two tested cones, and the one without a tail cone, converge at about $C_L = 0.6$ and have stability that increases with cone diameter. For the case of the 45-degree glide configuration, the cone diameter is about midway between the large and small cones. The predicted pitching moment curve is interpolated between them and shows stable slope of $dCm/dC_L = -0.16$, and has zero moment at $C_L = 0.7$. If the c.g. is moved forward 3 percent of the wing chord, the new stability level will be -0.19 and the moments will balance at $C_L = 0.6$, as desired. A similar exercise with a drag cone sized for the 30-degree glide angle would result in a stability level of $dCm/dC_L = -0.12$ and require a shift of the C_L to a point 4 percent rearward from the tested position of 25 percent mean aerodynamic chord.

It is thus evident that a glider may be designed with a range of glide angles by choosing the drag cone size, and that longitudinal stability and control can be achieved by properly locating the center of gravity. The point of zero moment might also be adjusted by changing the incidence of the horizontal tail, but since no data on tail effectiveness was taken with the delta wing, that method was not utilized here.

The wing incidence angle would also be raised approximately 5 degrees so that the wing will fly at $C_L = 0.6$ with body level.

3. Lateral Stability Analysis

Two parts of the lateral stability problem are important:

- The requirement to show that a spirally stable configuration can be achieved.
- That it is necessary to examine the effect on the final trajectory of the conditions of launching. These are an initial cross current and the possibility of errors in the launch attitude. This section will have four parts:
  - Analysis methods and choice of configuration
  - Extraction of derivations from data
  - Results of analysis
  - Effects of initial conditions

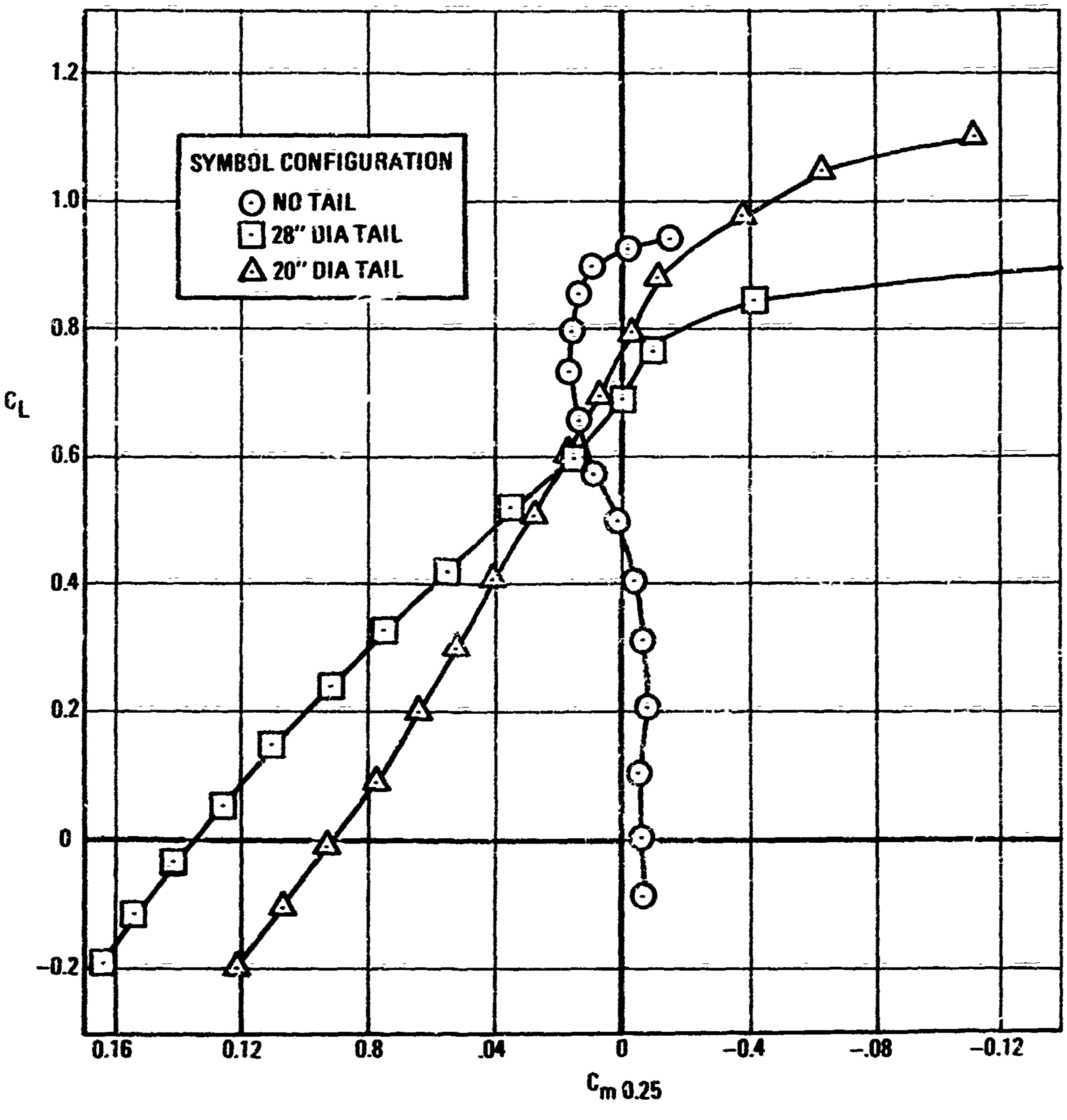


Figure 3. Pitching Moment Curves

a. Method of Analysis

(1) Spiral Stability Analysis

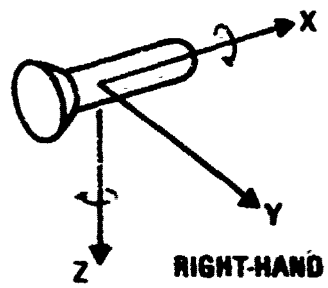
The equations used were standard equations taken from aircraft practice, linearized, small-perturbation equations in three degrees of freedom. Reference: *Stability and Control of Airplanes and Helicopters*, by Edward Seckel (1964 Academic Press).

Three equations are written with respect to a system of axes in the body, and oriented along and perpendicular to the flight path. They are

SIDEFORCE

ROLLING MOMENT

YAWING MOMENT



RIGHT-HAND AXES

The equations are LaPlace transformed from a system of linear homogeneous differential equations to a set of algebraic equations in which the variable, S, is the LaPlace operator. The transformed equations are, in matrix form

$$\begin{bmatrix} S-Y_V & U & -g\,\mathrm{Cos}\,\theta_0 \\ -L_V & -L_r & S^2-L_pS \\ N_V & S-N_r & -N_pS \end{bmatrix} \begin{Bmatrix} v \\ r \\ \phi \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \\ 0 \end{Bmatrix}$$

In which

U = Velocity of flight
θ_o = Initial angle of flight with respect to the horizon
Y_v = Side force derivative with respect to side velocity
L_v = Rolling moment derivative with respect to side velocity
L_r = Rolling moment derivative with respect to yaw rate
L_p = Rolling moment derivative with respect to roll rate
N_v = Yawing moment derivative with respect to side velocity
N_r = Yawing moment derivative with respect to yaw rate
N_p = Yawing moment derivative with respect to roll rate
v = Lateral velocity, LaPlace transformed
r = Yaw rate, LaPlace transformed
θ = Roll angle, LaPlace transformed

The characteristic equation is simply the determinant of the matrix set equal to zero, and the roots of the equation are the values of S which satisfy the equation. There are four roots, since expansion of the equation results in a 4th degree polynominal.

$$\lambda^4 + C_3\lambda^3 + C_2\lambda^2 + C_1\lambda^1 + C_o = 0$$

For any reasonable configuration, the roots are typically two real roots and one complex pair, i.e.

$$\lambda_1, \lambda_2, \lambda_R \pm i\,\lambda_2 t$$

The solution to the transient motion of the vehicle is then the inverse transform, and is of the form

$$Ae^{\lambda_1 t} + Be^{\lambda_1 t} + Ce^{\lambda_R t}(e^{i\lambda_i t} + e^{-i\lambda_i t})$$

The two real roots describe principally the roll and spiral motions. the roll root, usually large and negative, describes the rate at which a rolling velocity is damped. It is usually of interest only in control problems. The spiral root describes the way an initial turning disturbance is either damped or diverges, depending on the sign of the root. The value of this root is usually very small and, in airplanes, is usually positive, indicating instability. The object of this investigation was to make this root negative and as large as possible for rapid convergence.

The complex pair of roots represents an oscillatory motion called Dutch roll, in which rolling and yawing motions are coupled. The imaginary part of the root represents the frequency in radians per second, and the real part is the converging or diverging nature of the motion. This motion is usually only lightly damped, corresponding to a small, negative, real part of the root. Attempts to improve spiral stability usually cause the real part of the Dutch roll root to move in the positive or unstable direction.

Solutions of the equations are often presented by plotting the roots on the complex plane, in which the real axis is the abscissa and the imaginary axis is the ordinate.

(2) Choice of Configuration and Data

In the spiral analysis it was assumed that longitudinal stability and trim existed, and that the model would fly at a body angle of attack of zero degrees, which corresponds to the recorded data.

As before, only the delta wing configuration was analyzed, because of the non-linearity of the data for the straight wing. To avoid any unnecessary interpolation or extrapolation of data, only the tested cone sizes were used, even though they did not give the exact glide angle desired. At least one of the configurations, the small cone, would glide in the range between 30 and 45 degrees. The only extrapolation of characteristics necessary is the effect of changing the wing dihedral. Test data is available at 0 and 10 degrees for the large drag cone and was assumed to be linear. Dihedral effect was assumed to be the same for the glide-out anchor with the small tail cone. Projections were made in all the derivatives affected by dihedral angle up to 30 degrees. All other derivatives used in the analysis were extracted from the wind tunnel data.

Calculations of the inertial moments were made, assuming the use of solid cast iron construction for the body and drag cone, and steel plate for the wing and tail surfaces. The virtual mass of affected water was included in the mass and moment of inertia characteristics.

b. Analysis Results

Results of the analysis are presented in the form of plots of the complex roots of the characteristic equation (Figures 4 and 5). There are two real roots, and a complex pair. The real roots are negative if stable motion exists, and positive if unstable. The complex pair represents an oscillatory motion, having a frequency given by the imaginary component of the root, and a damping term given by the real component. The real component must be negative for stability.

The two configurations analyzed in Figures 4 and 5 are stable in all respects for dihedral angles from 0 to 30 degrees. The larger value of real root represents a rapid, damping in-roll characteristic of winged vehicles, and is of no concern for the purpose of this report.

The smaller real root represents the spiral mode, and is the principal object of this investigation. The value of this root is small and indicates a long characteristic time for any disturbed motion to subside.

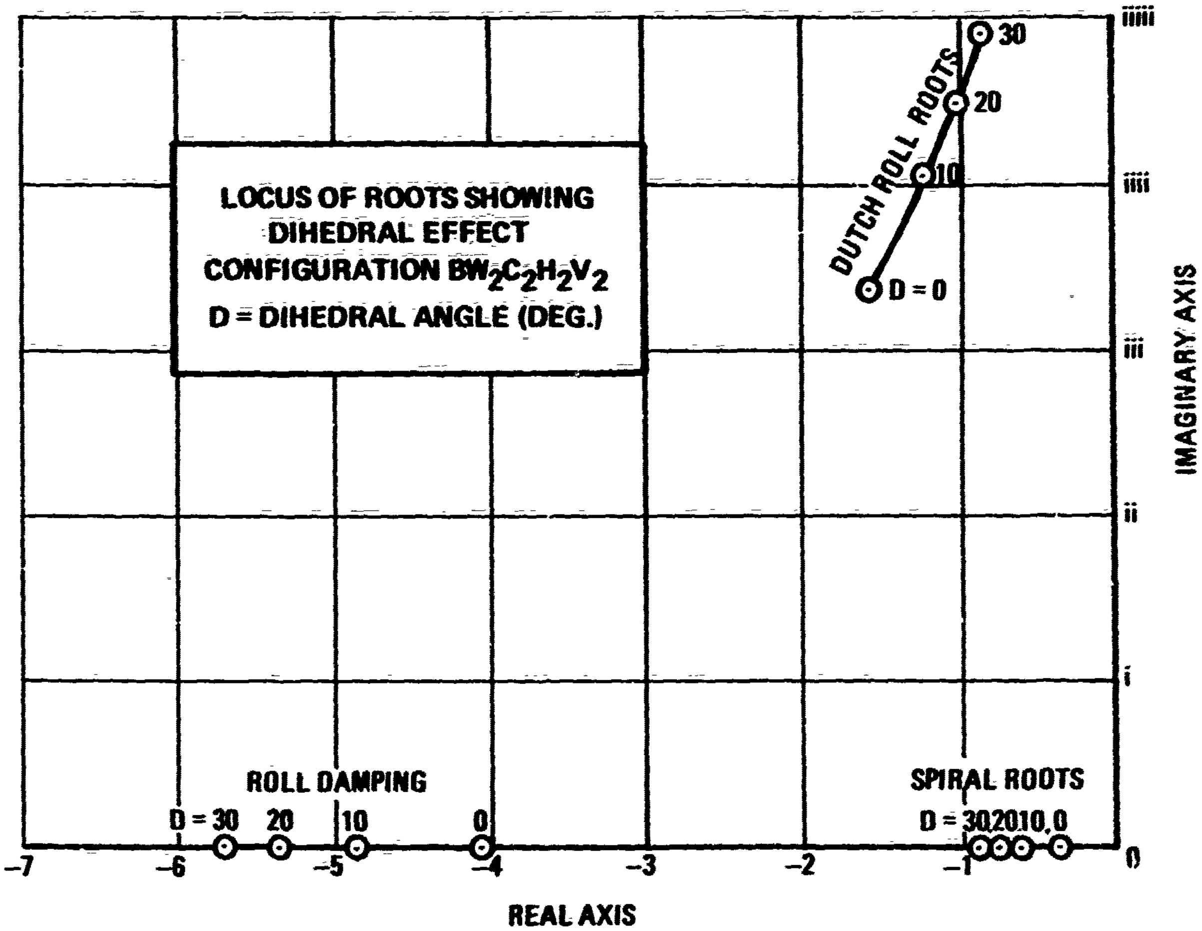


Figure 4. Dihedral Effect

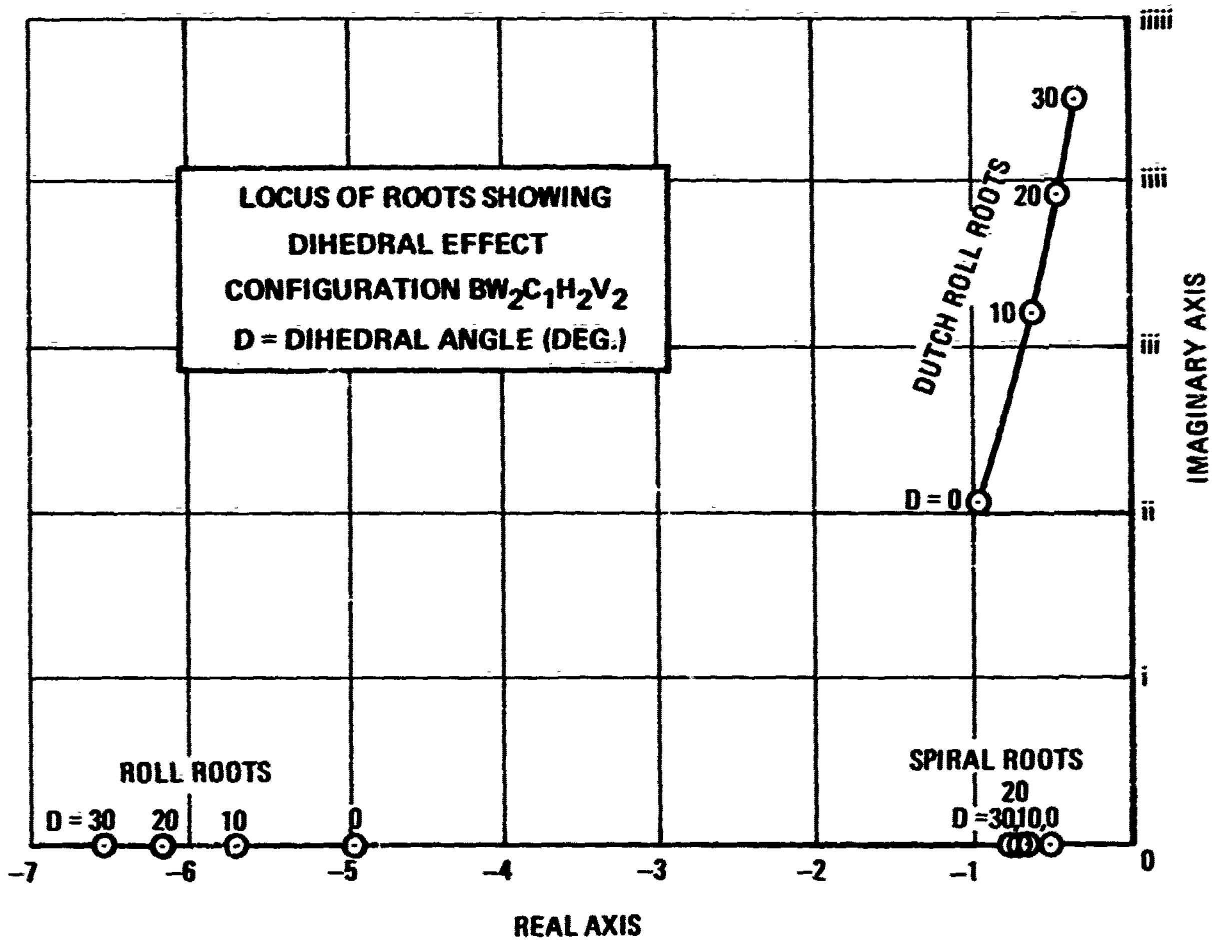


Figure 5. Dihedral Effect

It is clear that increasing the dihedral angle from 0 to 30 degrees increases the root and improves the spiral stability by a factor of 2 for the small cone and more than 2 for the Glide-Out Anchor with the large drag cone.

The complex pair represents a combined rolling-yawing oscillation (known as Dutch roll in aeronautical terminclogy). The only concern with this root is that the motion remains stable. As the dihedral is increased, the frequency rises, and damping attenuates. In no case do these motions become unstable.

4. Launch Errors

Two types of initial launch errors should be considered: (a) those due to a cross current, and (b) those due to an initial roll angle.

a. Cross-Current

Errors in trajectory, due to a cross current, may be analyzed by considering a launch with the model at an initial angle of yaw, i.e., pointing to one side of the path of the launcher. The unsymmetrical launch will result in some oscillatory motion due to the Dutch roll roots, and, if spirally stable, a final value of the heading angle will result. This final value can be found by application of the final value theorem to the LaPlace Transformed equation.

The final heading given by this process is zero. The meaning of this is that the GOA, when launched, may oscillate over a rather small amplitude, but will eventually settle down to its initial heading. It will, of course, drift with the current and land at some distance down current.

b. Roll Errors

The effect of initial roll errors is found in a similar way. The final value theorem is applied to the transformed equations, and the final heading angle is not zero, but is given by the following equation:

$$\psi_{error} = \frac{\phi_o}{\cos\theta_o} \left[\frac{L_r N_p - L_p N_v}{L_v N_r - L_r N_v}\right]$$

This equation means that if some initial roll angle exists, or is induced by launching into a cross current, the glider will turn in the direction of initial roll. After some oscillations (given by the Dutch roll roots) it will settle down on a final heading which is not the initial one, and an error in landing point will result. The magnitude of this error depends on initial roll derivatives. For a typical configuration, about one degree of heading results from one degree of initial roll error. A tabulation shows the sensitivity to dihedral angle for a chosen configuration.

	Large Cone				Small Cone			
Dihedral Angle	0	10	20	30	0	10	20	30
ψ/t	1.22	0.687	0.528	0.448	1.25	0.795	0.668	0.595

CONCLUSIONS

This study had two main goals:

a. To reduce the Glide-Out Anchor sensitivity to cross currents

b. To develop a configuration that would have a less steep glide path to the sea floor than the existing Glide-Out Anchor

Both goals were accomplished during the study, and in addition, the large number of wind-tunnel tests, of the various configurations, have shown that the Glide-Out Anchor concept is an inherently stable device that can be modified within fairly wide ranges to meet a wide range of performance requirements.

A primary purpose of this study program was to improve the azimuthal accuracy of the GOA when gliding in a cross current. The study showed that the Glide-Out Anchor itself is stable and can be made to maintain the desired accuracy of ±5 degrees over that caused by normal drift in cross-currents, assuming a good launch. The unexplained azimuthal errors that resulted during the last in-water test program were apparently the result of errors introduced during launch by the present launcher design. An improved launcher release system should eliminate this effect.

A second goal of the study was to develop an anchor design that had a less steep glide path to the sea floor than the existing Glide-Out Anchor. The wind-tunnel data and resulting analysis has shown that the Glide-Out Anchor can be easily modified to glide at angles ranging from 30 to 45 degrees, as measured from the horizon, by varying the tail cone size.

The final configuration selected to meet the program goals utilizes the delta wing with either 10 or 20 degrees of dihedral, and a 15-degree incidence angle. The tail cone size would be selected, based upon the desired glide angle. For a 30-degree glide, as referenced to the horizontal, a drag cone 1.7 times the diameter of the anchor body would be required.

For a 45-degree glide angle, a drag cone 2.4 times the body diameter would be required. The larger of the two stabilizers and tails tested would be utilized. These configuration choices were based on both the results of this study and on previous experience.

The final choice of wing dihedral angle, and exact tail-cone size would be made by in-water testing.

To further develop the Glide-Out Anchor, and to verify the results of this study, an in-water test program will be necessary.

ALL