Engineering Notes

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Glide Performance of Advanced Parawings

William C. Sleeman Jr.*
NASA Langley Research Center, Hampton, Va.

Introduction

A CONSIDERABLE amount of parawing research and technology work has been accomplished in the past two years, and this paper presents highlights of some of this work. Results of recent wind-tunnel tests of advanced twin-keel parawings are presented to indicate the improvements in performance obtained with these advanced configurations. Results of radio-controlled flight tests and simulator studies are also given to indicate the capabilities of piloting a gliding parawing vehicle to a landing at a desired point.

Performance Summary

A summary of maximum lift-drag ratios obtained in wind-tunnel tests of small-size twin-keel parawings is presented in Fig. 1. The planform sketches identify each configuration developed in two systematic wind-tunnel investigations of twin-keel parawings having the same formed nose at the center panel The first series of wings, which includes wings 1–10, was investigated by R. L. Naeseth and is reported in Ref. 1; the second series was investigated by P. G. Fournier and is reported in Ref. 2.

A preliminary assessment of the results of the two investigations suggested that the maximum lift-drag ratios increased with increasing extent of the center panel. Attempts to relate the two investigations on the basis of either center panel area ratio or total wing aspect ratio were unsuccessful. One basic difference in the two studies was the manner in which the planform varied when the keels were canted. In the first investigation,[1] the leading-edge sweep of the flat pattern was held fixed; whereas, in the second investigation, the outer panel geometry remained fixed and the leading-edge sweep angle was decreased by the amount of the keel cant angle. The parameter shown in Fig. 1, which combines both the center panel area ratio and the cosine of leading-edge sweep, appears to relate the data from the two investigations fairly well.

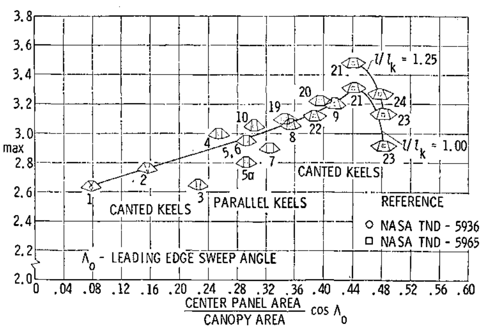

Fig. 1 Performance summary of twin-keel parawings having a formed nose.

Model 5 was the twin-keel configuration selected for development of deployment technology at large size in the recent Langley contract (The Northrop Corp., Ventura Div.). The more recent investigation of canted keels started with the same planform as model 5 (labeled as model 5a) and held the center panel nose width fixed as the keels were canted outward 5°, 10°, 15°, and 20° (models 19, 20, 21, and 24). Model 21 (15° cant angle) was modified by making the center panel narrower (model 22) and wider (model 23) to study effects of center panel width at 15° cant angle.

The results of Fig. 1 show that the maximum lift-drag ratio of the basic twin-keel 5 could be increased 0.3 by 15° cant of the keels. Increasing the line lengths of the 15° canted wing provided a maximum L/D value 0.5 higher than that of the basic parallel keel model 5.

Performance Characteristics of Advanced Twin-Keel Parawing

The lift-drag ratio and resultant-force coefficient performance parameters for the twin-keel wing having the highest value of maximum lift-drag ratio shown in Fig. 1 are presented in Fig. 2. The modulation shown for these parameters from tethered wind-tunnel test data was acheived with various combinations of rear keel line lengths and tip line lengths. These results show that the lift-drag ratio could be modulated from 3.48 to 2.30, and the resultant force varied from 0.83 to 1.22. The significance of these characteristics, as regards the expected flight characteristics, is not readily apparent, and these characteristics have been combined with assumed wing loading values to obtain vertical and horizontal velocities.

Glide Velocities for Advanced Twin-Keel Parawing

Glide velocities for twin-keel model 21 are given in Fig. 3 for assumed wing loading values of 1, 2, and 4; lines of constant lift-drag ratio are also shown. The maximum vertical velocities shown in Fig. 3 are relatively low—10 fps for a wing loading of 1.0 and around 20 fps for a wing loading of 4.0. The amount that the vertical velocity could be varied

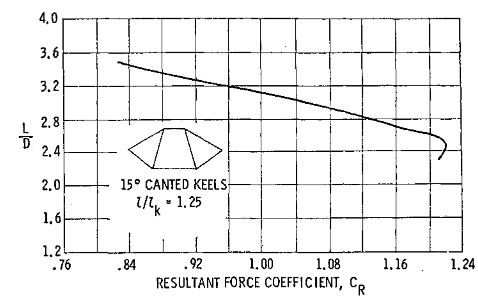

Fig. 2 Performance characteristics of an advanced twin-keel parawing.

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* Head, Vehicle Concepts Section. Associate Fellow AIAA.

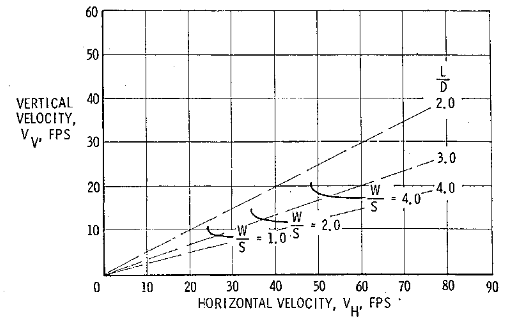

Fig. 3 Glide velocities for an advanced twin-keel parawing having 15° canted keels.

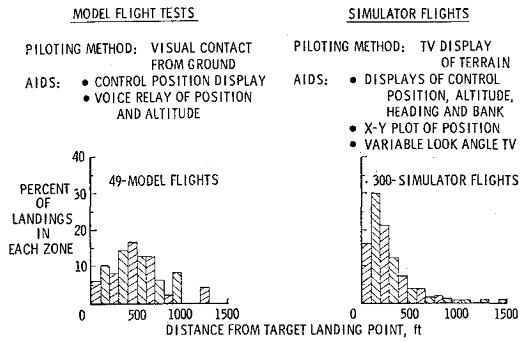

Fig. 4 Landing accuracy for parawing vehicle flights.

by control deflection at a given wing loading was almost insignificant. The horizontal velocity for a given wing loading could be varied a small amount, but not enough to provide the capability of good wind penetration and low landing speeds. These results indicate that, for the method of control used, the longitudinal controls will probably serve best as a means of trimming to obtain maximum lift-drag ratio rather than as a means for varying the flight velocity or glide path.

Landing Accuracy for Parawing Vehicles

The ability to control the flight heading and negotiate winds has long been cited as an advantage of gliding descent systems over a conventional parachute; however, quantitative information on landing accuracy of gliding systems has not been available. NASA has been interested in determining to what extent the advantages of the gliding descent system over a parachute system can be used to land a manned spacecraft at a desired touchdown point. Two research techniques were used to investigate the glide and landing of a lifting-body-parawing vehicle. Radio-controlled flights of a 300-lb vehicle were made at Wallops, and many simulator flights were made at Langley.

Model flight tests

Although parawing flight vehicles possess advantages over parachute systems, there are unusual flight characteristics in comparison to a conventional aircraft that could limit the ability of a pilot to land at a desired point. Some of the unusual flight characteristics of the lifting-body-parawing vehicle are 1) low flight velocities—of the same magnitude as typical wind velocities; 2) relatively long time to respond to a control input; and 3) very limited capability to vary the glide velocity and the aerodynamic flight-path angle in straight gliding flight.

A preliminary flight investigation of a lifting-body-parawing vehicle was undertaken to develop operations procedures and train radio-control pilots for conducting research flights. Achievement of landing accuracy was not one of the objectives of these tests; however, the range safety guidelines called for landings to be within 800 ft of the target point.

The radio-controlled flights were conducted with the pilot located several hundred feet from the target, and the vehicle was flown by a stick-type hand control. The pilot viewed the vehicle from the ground after it was dropped from a helicopter and flew it by visual contact to landing touchdown. Drop altitudes varied from 700 ft to 4000 ft and the average descent rate was approximately 1000 ft/min.

Landing-point data from the lifting-body flight tests are given in Fig. 4 in the form of percentage of landings in 100-ft zones out from the target landing spot. These results show that 86% of the landings were within the desired 800-ft radius. This score is very good considering the fact that none of the five pilots were trained and that the little experience gained by each was under conditions of high stress. The test area was surrounded by forbidden areas that contained ground facilities, and the stress of conducting flights in a manner to avoid these areas prevented attainment of any significant amount of pilot training.

Simulator flights

The flight tests indicated a need for effective training of radio-control pilots and more adequate information display for the pilot. A simulator program was initiated by G. K. Miller at the Langley Research Center to meet these needs. A six-degree-of-freedom simulation for a rigidly coupled wing-body system was performed. A television camera on a motorized track scanned an Earth terrain photograph of the test range used in the flight tests. The pilot provided control inputs to the computer, which drove the television camera in response. A scan-optic system was used to provide rotational simulation about all three axes. In addition to the television display of the Earth terrain, the pilot had displays of altitude, bank, heading, control position, X-Y position, and camera scan angle.

Landing-point data for the 300 simulator flights are presented in Fig. 4. These results show that about 95% of the landings were within 800 ft of the target landing point. In contrast to the free-flight tests, a large percentage of the simulator flights were less than 400 ft from the target. The improved accuracy for the simulator flights can be attributed to the use of adequate pilot displays and the actual training that was gained in flying several wind profiles.

Observations from Pilot Experience

The experience gained from the free-flight tests and the simulator runs provided a background of information that permits some pertinent observations to be made on flying a parawing vehicle. 1) A parawing vehicle can be controlled and landed at a selected site provided the wind offset is within the capabilities of the glide to reach the target area. If the wind offset is excessive, an alternate site must be used. 2) Large turn rates were not required; in fact, the use of large turn control inputs generally caused overcontrol. The vehicle was easier to control when only one-quarter of the available turn control deflection was used. 3) Flying the vehicle by visual contact from the ground was a difficult task. The vehicle could be successfully flown and landed without visual contact by the use of displays of control position, altitude, heading, and X-Y plot location of vehicle. These observations are based on the experience of average radio control pilots, and it can be assumed that highly skilled pilots with considerable experience with a particular vehicle and landing area could perform the task with less display information. 4) Various flight techniques could be used successfully to land near the desired target for a given wind condition. For example, a long crosswind approach leg with a turn into the wind for landing; circling the target and straightening into the wind with snaking to use up excess altitude before landing; flying downwind of the target and making a long straight approach into the wind; or holding into a high wind until some penetration is evident, then adjusting altitude and range relationship by gentle heading changes. 5) The ability to see directly beneath the vehicle as well as ahead is needed when flying a terrain display in order to determine the X-Y position of the vehicle. 6) Continuous or rapid turns frequently caused the pilot to become disoriented when using a terrain display. Reorientation could generally be obtained by reference to the heading and recognizable terrain features. The landing area should, therefore, contain easily distinguishable markings for providing visual cues to both location and heading.

References

[1] Naeseth, R. L., "Low-Speed Wind-Tunnel Investigation of a Series of Twin-Keel All-Flexible Parawings," TN D-5936, 1970, NASA.

[2] Fournier, P. G., "Low-Speed Wind-Tunnel Investigation of All-Flexible Twin-Keel Tension-Structure Parawings," TN D-5965, 1970, NASA.

Added Mass in Roll of a Four-Finned Configuration

Y. K. Chung*

Oceanics Inc., Plainview, N.Y.

In presenting his version of the slender-body theory almost two decades ago Bryson[1] published a formula for the nondimensional added mass in roll A_{13} of a configuration consisting of four fins mounted on a circular body. A second formula to which the first reduces when the body shrinks to zero was also published. Soon after, he discovered an error in these results and published a correction.[2] More recently a computer program has been prepared at Oceanics Inc. for calculating the loads on tail assemblies undergoing an arbitrary maneuver. As part of the program the added masses in roll for these configurations were required and the result for A_{13} was rederived. It was found that the corrections that Bryson published[2] are in error. Indeed, the true formula cannot be expressed in closed analytical form in terms of elementary functions except for the case of no body. As a consequence a subroutine for calculating A_{13} numerically in terms of quadratures was prepared. There does not appear to be any reason to publish the correct formula for the complete configuration at this time since it is very complicated and has already been incorporated into a computer program that is available. For the simpler case of no body, however, results can be obtained readily using hand computation if desired, and so the correct formula is presented below using Bryson's notation.

$$A_{13} = -(2/\pi D^3)(\tfrac{1}{2}h + f)^3 \, [\tfrac{2}{3} \sin^3\theta_0 - \tfrac{2}{3} \sin^3\theta_3 -$$
$$\tfrac{1}{2} (\cos\theta_0 - \cos\theta_3) \, (- \tfrac{1}{2}\pi + \theta_0 + \theta_3 - \tfrac{1}{2} \sin 2\theta_0 - \tfrac{1}{2} \sin 2\theta)]$$

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* Senior Scientist.

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[1] Bryson, A. E., "Stability Derivatives for a Slender Missile with Application to a Wing-Body-Vertical-Tail Configuration," *Journal of the Aeronautical Sciences*, Vol. 20, No. 5, May 1953, pp. 297–308.

[2] Bryson, A. E., "Comment on the Stability Derivatives of a Wing-Body-Vertical-Tail Configuration," *Journal of the Aeronautical Sciences*, Vol. 2, No. 1, January 1954, p. 59.