Engineering Notes

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Wind Shear Payload Support System

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Nomenclature

A_A, A_p = reference area of drag area and parawing, respectively
C_{D_A}, C_{D_p} = drag coefficient of drag area and parawing, respectively
C_{L_p} = lift coefficient of parawing
D_A, D_p = drag force acting on drag area and parawing, respectively
h = payload altitude
Δh = altitude difference between drag area and parawing
L_p = lift force acting on parawing
L/D = lift to drag ratio of parawing
V_1, V_2 = wind velocity at drag area and parawing, respectively
V_h = wind velocity difference between drag area and parawing altitudes
V_{ground} = velocity of the system over the ground
V_{REL} = wind velocity relative to parawing
ΔV = drag area incremental velocity
ΔV_h = wind shear-sec^{-1}
W_{total} = total system weight
ρ_1, ρ_2 = atmospheric density at drag area and parawing, respectively

Introduction

THE desire to support small payloads in the atmosphere for long periods of time using systems without internal sources of power has existed for some time. Any passive aerodynamic device which is used to support a payload in the atmosphere will sink unless it can extract energy from the atmosphere. One energy source that might be utilized is the wind shear. A high statistical probability exists[1,2] for a wind shear of at least 5 knots/1000 ft altitude from the Earth's surface to 30,000 ft altitude. In this Note, the results of a preliminary investigation of a concept which utilizes two connected aerodynamic bodies which operate at different altitudes and extract energy from wind shear to maintain the system in flight are described.

Wind Shear System

The wind shear support system which utilizes a parawing for the upper-body and a drag area for the lower one is shown in Fig. 1. A parawing was selected for the lift producing vehicle, rather than a kite, because of its greater aerodynamic efficiency, i.e., L/D. System operation is obtained by balancing the forces acting on the system in both the vertical and horizontal directions. The lift force of the parawing balances the total system weight while the drag force of the drag chute is in equilibrium with the parawing drag.

The wind velocity V_2, at the parawing altitude is higher than the velocity, V_1, at the drag chute due to wind shear by the amount V_h

$$V_h = (V_2 - V_1) = \Delta V_h \Delta h \tag{1}$$

Received June 6, 1972: revision received December 1, 1972. Work supported by AFSC Aeronautical Systems Division, under Contract F33657-70-c-1052.

Index category: Aircraft Performance.

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Equilibrium between drag forces of the drag area and parawing requires that the drag area move an incremental velocity ΔV faster to the right of Fig. 1 than the wind velocity V_1 at the drag chute altitude. This incremental velocity acts on the drag area and produces a drag force of magnitude

$$D_A = C_{D_A} 1/2\rho_1(\Delta V)^2 A_A \tag{2}$$

The velocity of the system over the ground is the sum of the wind velocity V_1 and the incremental velocity ΔV while the velocity relative to the parawing is the difference between the wind velocity difference V_h and ΔV.

It is the relative wind velocity to the parawing that produces the lift and drag forces acting on the parawing

$$L_p = C_{L_p} 1/2\rho_2(V_{\text{REL}})^2 A_p \tag{3}$$

$$D_p = C_{D_p} 1/2\rho_2(V_{\text{REL}})^2 A_p \tag{4}$$

The force balance requires that the parawing lift L_p equal the system weight W_{total} and that the parawing drag D_p equal the drag area force D_A (neglecting the drag of the connecting wire). These force balance equations may be solved to determine the parawing and drag areas as a function of the relative velocity V_{REL} once the total system weight W_{total}, operating altitude h, altitude difference Δh, C_D of the drag area, C_L and C_D of the parawing and ΔV_h of the atmosphere are chosen.

Example System

The variation of parawing and drag chute area as a function of relative velocity is shown in Fig. 2 for operating altitudes of 0, 5000, and 10,000 ft for a system with a one pound weight under the simplifying assumption that $\rho_1 = \rho_2$. The parawing characteristics and other parameters selected for the example calculation are noted below

$$C_{L_p} = 0.92, \quad C_{D_A} = 1.17$$
$$C_{D_p} = 0.27, \quad \Delta h = 2000 \text{ ft}$$
$$L/D = 3.4, \quad \Delta V_h = 5 \text{ knots (8.65 fps)/1000 ft}$$

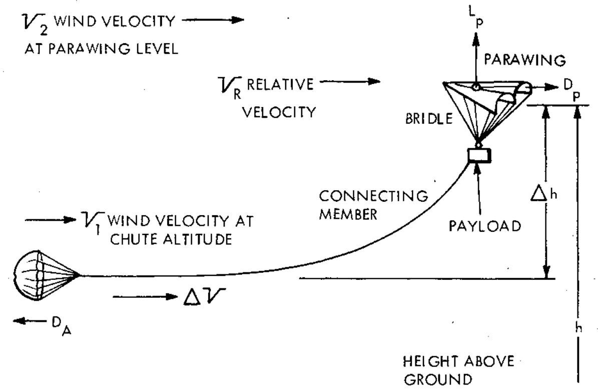

Fig. 1 Wind shear payload support system.

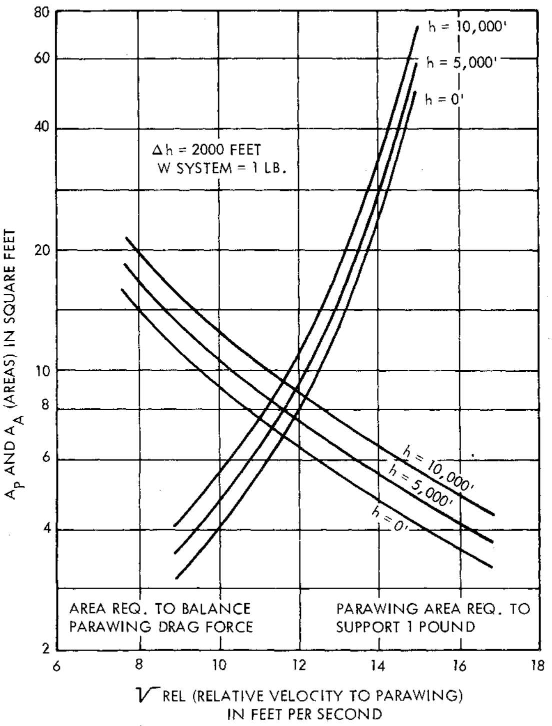

Fig. 2 Required parawing and drag areas.

The parawing characteristics are typical of rigid frame conical canopy parawings,[3,4] conical canopy parawings with large diameter leading edges[5] and the best of the all-flexible twin-keel parawings.[6] Substantially higher L/D ratios can be obtained but they require the use of solid or cylindrical canopies[7] with rigid frames.

Reasonable size parawing and drag areas result if the relative velocity is chosen near 12 fps. If a design point of h = 5000 ft is chosen, the area of the parawing and drag area are A 8.00 ft^2 for V_{REL} = 11.65 fps.

The parawing and drag areas for the design point (A_p = A_A = 8.00 ft^2) have a combined weight (including suspension lines) of two ounces if made from ½ MIL reinforced mylar film. The music wire member which connects the parawing and drag areas is 5800 ft long for Δh = 2000 ft, has a diameter of 0.002 of an inch and weighs one ounce. The weight estimate for the wire assumes a minimum tensile strength of 475,000 psi (Ref. 8) and a factor of safety of 1.5. The system may be packaged in a volume of only a few cubic inches. The system payload may be increased further by the use of a second parawing instead of the drag chute.

The operating altitude of the wind shear system is sensitive to changes in the magnitude of the wind shear since the lift force varies as the square of this quantity. The wind shear system will ascend or descend until a sufficient change in ambient density occurs to produce the original lift force at the new operating altitude and altered wind shear magnitude. For long duration flights where the wind shear may change from the value at launch, flight at the minimum expected wind shear level may be assured by off-loading payload from a given design or by using a system which is sized for this condition. The system may be set up in its flying configuration and ground launched like a kite or dropped from an aircraft.

Conclusions

A wind shear payload support system using two connected aerodynamic bodies which operate at different altitudes and extract energy from wind shear to maintain the system in flight is a feasible concept. An example of such a system which has a parawing for the upper body and a drag area for the lower one is considered for support of a total system weight of one pound. The combined parawing and drag areas are found to total less than 20 ft^2 for an altitute separation of 2000 ft and payloads of 50% or more of the total system weight are possible.

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Vibrations of an Euler Beam with a System of Discrete Masses, Springs, and Dashpots

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Introduction

THE present work analyses the vibrations of an Euler beam carrying masses and having spring-cum-dashpot supports at discrete points. The work is an extension of the work done by Pan[1,2] and generalizes the works done by McBride[3] and Das.[4] The discrete elements are included in the equation of motion through Dirac delta functions. The equations of motion resulting from the eigen expansion are uncoupled with the help of coordinate defined by Foss,[5] where displacements and velocities are treated separately. As an illustration, response to landing impact of an aircraft wing-fuselage-landing gear system is worked out.

Equations of Motion

Consider an Euler beam (length L, mass/unit length m, and rigidity EI) carrying masses M_i, springs K_i, and/or dashpots C_i at distances x_i (i = 1-N). The equation of motion for free vibration $y(x,t)$ may be written as

$$\frac{\partial^4\eta}{\partial\xi^4} + \sum_i^N \psi_i\delta(\xi-\xi_i)\eta + [1 + \sum_i^N \mu_i\delta(\xi-\xi_i)]\frac{\partial^2\eta}{\partial\theta^2} + \sum_i^N \zeta_i\delta(\xi-\xi_i)\frac{\partial\eta}{\partial\theta} = 0 \quad (1)$$

Received August 14, 1972.
Index category: Aircraft Landing Dynamics.
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